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ENERGY RESOURCES AND NATIONAL POLICY

REPORT OF THE
ENERGY RESOURCES COMMITTEE
TO THE
NATIONAL RESOURCES COMMITTEE

NATIONAL RESOURCES COMMITTEE
JANUARY 1939

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MESSAGE FROM THE PRESIDENT

To the Congress of the United States:

In accordance with my request of March 15, 1938, the National Resources Committee, in consultation with the other Federal agencies concerned, has prepared a comprehensive study of our energy resources, which I present herewith for your consideration.

This report represents the joint effort of many specialists both within and outside the Federal Government. It suggests policies, investigations, and legislation necessary to carry forward a broad national program for the prudent utilization and conservation of the Nation's energy resources.

Our resources of coal, oil, gas, and water power provide the energy to turn the wheels of industry, to service our homes, and to aid in national defense. We now use more energy per capita than any other people, and our scientists tell us there will be a progressively increasing demand for energy for all purposes.

Our energy resources are not inexhaustible, yet we are permitting waste in their use and production. In some instances, to achieve apparent economies today future generations will be forced to carry the burden of unnecessarily high costs and to substitute inferior fuels for particular purposes. National policies concerning these vital resources must recognize the availability of all of them; the location of each with respect to its markets; the costs of transporting them; the technological developments which will increase the efficiency of their production and use; the use of the lower grade coals; and the relationships between the increased use of energy and the general economic development of the country.

In the past the Federal Government and the States have undertaken various measures to conserve our heritage in these resources. In general, however, each of these efforts has been directed toward the problems in a single field: Toward the protection of the public interest in the power of flowing water in the Nation's rivers; toward the relief of economic and human distress in the mining of coal; or toward the correction of demoralizing and wasteful practices and conditions in the industries producing oil and natural gas. It is time now to take a larger view: To recognize—more fully than has been possible or perhaps needful in the past—that each of our great natural resources of energy affects the others.

It is difficult in the long run to envisage a national coal policy, or a national petroleum policy, or a national water-power policy without also in time a national policy directed toward all of these energy producers—that is, a national energy resources policy. Such a broader and integrated policy toward the problems of coal, petroleum, natural gas, and water power cannot be evolved overnight.

The widening interest and responsibility on the part of the Federal Government for the conservation and wise use of the Nation's energy resources raises many perplexing questions of policy determination. Clearly, there must be adequate and continuing planning and provision for studies which will reflect the best technical experience available, as well as full consideration for both regional and group interests.

Some Federal legislation affecting the energy resources will expire at the end of this fiscal year, other legislation at the end of a few more years. This report sets forth a useful frame of reference for legislative programs affecting these resources and illustrates another approach to the systematic husbandry of our natural resources. Specific recommendations are advanced for solution of the most pressing problems.

In order to facilitate its use by the Congress, I recommend that this report be printed together with the supporting staff reports and illustrations, when these are available in final form, in conformity with similar reports prepared by the National Resources Committee.

Franklin D. Roosevelt.

The White House,
February 15, 1939.

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ACKNOWLEDGMENTS

Grateful acknowledgement is made of the cooperation and assistance of the special contributors named above and of the several Federal bureaus and agencies concerned with the energy resources, especially the staffs of the Bureau of Mines, Geological Survey, and Petroleum Conservation Division of the Department of the Interior; the Federal Power Commission; and the National Bituminous Coal Commission.

LETTER OF TRANSMITTAL

National Resources Committee
Interior Building
Washington

January 28, 1939.

The President,
The White House.

My Dear Mr. President:

We have the honor to transmit a report on the energy resources of the Nation with recommendations for their prudent utilization and conservation in relation to each other and to the national economic structure.

In accordance with your request, the report has been prepared in consultation with all other interested agencies of the Government. It includes supporting papers by specialists from both inside and outside the Government, assembled and summarized by a staff under the direction of Dr. Ralph J. Watkins.

The findings and recommendations, in which we concur, point the way to a national policy for the prudent conservation and wise use of our energy resources.

Sincerely yours,

Harold L. Ickes
Secretary of the Interior, Chairman

Harry H. Woodring,
Secretary of War.
H. A. Wallace,
Secretary of Agriculture.
Harry L. Hopkins,
Secretary of Commerce.
Frances Perkins,
Secretary of Labor.

F. C. Harrington,
Works Progress Administrator.
Frederic A. Delano,
Charles E. Merriam,
Beardsley Ruml,
Henry S. Dennison.

NOTE

Attention is directed to the fact that since this report was completed, the National Bituminous Coal Commission has been abolished under the President's Reorganization Plan No. 2 and its powers, duties, and functions transferred to the Secretary of the Interior. Also, the Connally Act regulating interstate and foreign commerce in petroleum, which would have expired on June 30, 1939, has been extended for an indefinite period by the Congress.

ENERGY RESOURCES AND NATIONAL POLICY

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ENERGY RESOURCES AND NATIONAL POLICY
FINDINGS AND RECOMMENDATIONS

By the National Resources Committee

Coal, oil, natural gas, and water power are the principal sources from which we have obtained the fuel and the electric energy for the heat, light, and power essential to our industrial civilization. In recent years the conservation of these great natural resources, their orderly development, their readiness in case of need for the national defense, and the preservation in economic health of the industries that make them available have become matters of national concern. We have realized that the abundance provided for our use by nature will not last forever; we are beginning to realize that the welfare of millions of our people is bound up in these great industries.

In the past the Federal Government and the States have undertaken various measures in order to conserve and to assure the wise use of these resources. In general, however, each of these efforts has been directed toward the problems in a single field: toward the protection of the public interest in the power of flowing water in the Nation's rivers; toward the relief of economic and human distress in the mining of coal; or toward the correction of the demoralizing and wasteful practices and conditions in the industries producing oil and natural gas. It is time now to take a larger view, to recognize more fully than has been possible in the past that each of these energy resources affects the others, and that the diversity of problems affecting them and their interlocking relationships require the careful weighing of conflicting interests and points of view.

Coal

Our coal reserves have been estimated at approximately 3,000 billion net tons, more than half this total representing low-grade bituminous coal and lignite. Total production to date has been about 23 billion net tons, the 1937 output amounting to a little under one-half billion tons. Almost 70 percent of our total reserve lies in the semiarid plains or in the Rocky Mountains, far from centers of population and industry. About 85 percent of present production is from the 30 percent of our reserves east of the Mississippi River.

The coal industry of the United States has suffered depression since 1923. This depression has been more acute in the anthracite than in the bituminous coal industry in recent years. As the deposits of anthracite are virtually confined to Pennsylvania, the difficulties of that industry have commonly been thought of as a State rather than as a national problem. This view may prove short-sighted, but thus far experience in Federal regulation—except for the period of the World War—has concerned only the bituminous industry. The following discussion, therefore, will be limited to bituminous coal.

The problems of the bituminous industry are not new. They go back to the sheer abundance of the underground reserves, and to the scattering of titles to those reserves among scores of thousands of owners, each of whom naturally has desired to realize upon his property by sale or development. This condition early led to the opening of great numbers of mines with a capacity far in excess of the national requirements. The surplus of capacity led to a chronic tendency to overproduction and the resulting chaotic price conditions. During the World War and a few years immediately following, coal shortages at home and abroad served to increase the capacity and the industry prospered, but after 1923 the shortages came to an end. Conditions in the industry since then have been characterized by surplus capacity, declining prices, cut-throat competition, and pressure on labor standards.

Following 1929, the position of the industry grew still worse, and Federal regulatory measures have been attempted. The current measure, the Bituminous Coal Act of 1937, is a crystallization of 25 years of investigation by the Congress and the Executive of the problems of coal mining. The act of 1937 represents a growing conviction that something had to be done. In bringing the coal industry under public regulation, the United States was repeating the experience of virtually every other coal-producing country, although our action was not conscious imitation; rather it is clearly traceable to national origins. The causes underlying this world-wide tendency are in large part the pressure of surplus coal-mining capacity.

What we are witnessing in the United States is probably the beginning of a continuing public control, which in some form or other will be a permanent national responsibility. It is therefore of the utmost importance that we build firmly now so that any subsequent modifications of approach can be intelligently made. The possible evolution of American policy toward the coal industry becomes clearer in the light of European experience. Continental and British control

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of coal mining began, like American, with the regulation of prices. But there has been a clearly defined tendency to supplement price control with cooperative marketing associations, or with the allotment of tonnage quotas.

Oil and Gas

Our proven oil reserves have been estimated at 15 billion barrels, in comparison with 1937 consumption of about 1¼ billion barrels. Our natural gas reserves have been estimated recently at from 60 to 100 trillion cubic feet, in comparison with 1937 production of somewhat more than 2 trillion cubic feet. Although discovery has more than kept pace with production of these resources, proven reserves are so small in comparison with annual consumption that these energy producers must be considered as strictly limited. With the Nation so dependent on liquid fuels particularly, it would certainly seem to be the part of wisdom to proceed cautiously in the use of this resource. Yet, today we are depleting our reserves of oil faster than the rest of the world. We must consider the possibility of being first among the oil-producing nations to feel the pinch. We must consider whether to use more wisely our available supply, to manufacture high-cost substitutes, or to depend on foreign oil for our motor cars and airplanes, our tractors, and our battleships. After our natural reservoir oil is exhausted or after the shortage becomes serious, we can turn to oil produced from coal, to oil-bearing rock or shale, or to alcohol from vegetable matter. But these processes make a liquid fuel available only at much higher costs. Consequently, although we need not be alarmed over the possible breakdown of our motorized civilization, we may well concern ourselves over the higher costs that we should have to pay after exhaustion of natural reservoir oil.

Although the various State systems of restricting production in flush pools were developed for another purpose, in many instances they have made a considerable contribution toward conservation. Still the problem of conservation has not been solved under the present State system of regulating production in the oil industry. State legislation compelling proration of oil pools has probably resulted in many instances in social savings, but under the present system of proration, the initiative lies with the States. The Federal Government is unable, except by suggestion, to initiate any general improvement in production procedure or in standardized regulation of the industry throughout the country; but if broad conservation measures are to be adopted for the oil and gas industry, only the Federal Government can be expected to initiate them. The competitive interests among producers and States are so strong that only the Federal authority can be relied on to bring forth strong conservation measures. The general goal of all Federal-State legislation affecting oil and natural gas should be to eliminate waste of these resources and to stretch the life of underground reserves over as long a period as possible without unduly restricting the more important uses of the products.

In many States the courts have already modified the rule of capture so that a landowner can recover only a certain amount of oil within a given period. Although the right of capture has been modified somewhat, it needs to be completely displaced by a thoroughgoing law of ownership in place, which would allot to each producer that proportion of the oil and gas in the common reservoir which underlies the land he owns or controls. The economic advantages of unit operation and scientific management of oil and gas pools are so overwhelming and so generally approved by technicians that some legal device of providing for their adoption and enforcement will surely be forthcoming as the threat of exhaustion becomes imminent.

Water Power

The use of water power in the United States is about as old as the industrial history of the country. It was not until invention of electric energy transmission, however, that the energy of falling water became available anywhere except at the power site. Today with modern transmission equipment, a large hydroelectric plant conceivably might supply electric energy anywhere within a circular area of 200,000 square miles centered at the fall, i. e., an area twice as large as the combined land area of the States of New York, Pennsylvania, and New Jersey, or considerably more than three times the area of all the New England States combined.

As a source of energy, water power affects and is affected by the available mineral fuels, but it differs from them in that it is not reduced by use. Water power, in sharp contrast with the mineral fuels, is an energy resource that renews itself. Our country would indeed be fortunate in some respects if all the demands for energy could be met by water power, but at best our water power resources can supply only a fraction of the Nation's energy requirements. It has been estimated, for example, that all our water power, including both that developed and that feasible of development, could produce energy annually equivalent to only about one-fourth of the energy contained in all mineral fuels consumed in the country in 1937 for all purposes.

Even the power requirements of the relatively near future will make necessary new supplies of energy exceeding the potential output of all the available and feasible undeveloped water-power sites in most industrial regions. A relatively small growth in the power load, surely to be expected under anything like normal conditions, will bring this to pass in a very few years. For example, the total amount of potential and feasible undeveloped water power within present economic transmission distance of the larger industrial and urban areas in the eastern half of the country would not supply even their present needs for electric energy without the aid of fuel.

In spite of this potential demand for water power, it is well to point out that the quantity of water power that will be available is greatly dependent on governmental policy. The storage and controlled release of water, which most of the potential water-power sites involve, requires an integrated policy of multiple use for the water resources affected. For the larger basins, an integrated policy of storage and use seems not within the scope of private enterprise, nor within State or municipal scope without Federal cooperation. Thus, the amount of practically available water power is very much dependent on the extent of Federal development.

There are rich possibilities for the development of water power as a joint purpose, in combination with other useful purposes to which a stream may be adapted or in combination with measures to control the stream for other reasons. Historically it is true that there have been water-power developments which impaired the usefulness of certain streams for other purposes, and certain streams may have been exploited in such manner as to foreclose or reduce their future usefulness for power. This Committee has in recent times pointed out that this apparent conflict can largely be resolved on many streams, and especially on great river systems, if our water resources are properly utilized and wisely controlled.

Recommendations

The obvious fields of remedy with respect to conservation of energy resources seem to lie (1) in promoting greater efficiency in the production of the fuel resources from the standpoint of recovery; (2) in promoting greater economy in the use of fuels; and (3) in placing a larger share of the energy burden on lower grade fuels and water power. To serve these objectives, the following recommendations are advanced:

1. *Coal.*—We believe that the problems of the bituminous-coal industry are too large for any one State to solve. The intensity of interstate competition makes the ills of the industry a matter of national concern and Federal responsibility. Some form of Federal regulation of bituminous coal is clearly necessary. The particular form of regulation that has been written into the Bituminous Coal Act of 1937 undoubtedly represented the majority opinion within the industry as the best approach to the problem, but a judgment on the effectiveness of the measure must be withheld until the act has become fully operative. Every opportunity should be provided for conclusive experiment with the system of controls which the law requires. It is well to bear in mind that although the act is limited to 4 years, the problem with which it deals is not a short-lived emergency. Whatever modifications the experience gained under the 4 years of life of the present act may suggest, the need for public supervision of the coal industry will remain permanently. Some means are required for effectively balancing production against requirements, whether by control of prices, by control of distribution, or by both. A less immediate but more fundamental need is to control the opening of new mines and retard expansion of capacity beyond reasonable requirements. Adequate safeguards must be provided for maintaining labor standards and protecting the rights of consumers by Government supervision of the system of regulation.

2. *Oil and gas.*—We propose that a Federal oil conservation board or commission should be created within the appropriate Government department to administer the Federal interest in the oil-and-gas industry and to make necessary rules and regulations concerning the production of and commerce in oil and gas. It should have the authority to require that oil and gas be extracted by such methods as are adequate to avoid waste and to protect the interest of all producers drawing from a common reservoir.

It is recognized that the development of minimum standards for the production and transportation of oil and gas designed to further the national interest in conservation of these resources is a complex problem, and that such standards should be developed in cooperation with the State regulatory agencies and the representatives of the industry. It is recommended, therefore, that the Connally Act be extended for such time as may be necessary for the framing and enactment of an adequate Federal oil-and-gas measure.

3. *Water power.*—The committee wishes to emphasize—as it has in its previous reports—that an active public policy of multiple-purpose development of water resources is desirable, particularly in view of the pressing character of problems related to flood control, public water supply, stream pollution, irrigation, and navigation. An active policy of public development of water power is likewise desirable under certain appropriate conditions. Both the development directly for power purposes, where there is no conflict with more urgent water control, and the best feasible use of the head made available by water storage for other purposes would contribute toward the attainment of three major national objectives, namely: (*a*) conser-

vation of scarce fuel materials—petroleum, natural gas, and the higher grade coals; (*b*) strengthening the national economy, through making cheaper electric energy more widely available; (*c*) strengthening the national defense, through assuring an ample supply of electric energy in time of war.

Multiple-purpose plans for stream development which are aimed at the several important purposes, including direct or incidental power production, should be designed and executed in terms of plans for whole drainage basins or major sub-basins. Design of the power system in any of the basin developments should include the best practicable interconnection (*a*) of the several plants within a basin system, (*b*) of neighboring basin systems (within the reach of economic transmission), and (*c*) of the steam capacity built or acquired to balance capacity. Federal policy should, in general, embrace eventual merging of private water-power plants into the system covered by any basin plan.

Transmission of electric energy is in many social and economic essentials closely akin to transportation of commodities. Particularly as the economic limits of transmission are extended, we believe that the national interest will be served best by coordinated systems of interconnections which will make available in wider markets energy derived from the most economical sources, regardless of whether they are large-scale hydro plants or efficient steam plants. Such coordinated systems would make the Nation less vulnerable to attack in time of war and less vulnerable to the emergencies of peace as well as better prepared for the continuing problems of peacetime development.

4. *Research.*—Both the production and the use of the mineral fuels are accompanied by a large waste of some of the most valuable resources of the Nation. Naturally, the fuels that are easiest to obtain and most convenient to use are being depleted most rapidly, leaving for future generations fuels more difficult of access, less suited to the uses for which they are required on the basis of present-day values, or lacking in the convenience that gives them form value. We believe that the supplies of these high-grade fuels can be protected from unnecessary depletion by research (*a*) to promote greater efficiency in production from the standpoint of the percentage of recovery, (*b*) to promote a greater economy in use, and (*c*) to fill a larger part of the demand for energy by the use of lower grade fuels.

Both fundamental and applied research should be stimulated and supported by the Federal Government in the agencies concerned with the energy resources, and this research work should be vigorously pointed in the direction of conservation of these resources, i. e., toward the efficient use of our energy resources in the interest of the national welfare, the avoidance of unnecessary waste in their production and utilization, and the safeguarding in economic health of the industries and populations on which we rely for the development of these vital resources. Much of this research function can be discharged only by the Federal Government, although important parts of it have been and should be discharged by the State governments, by educational and other quasi-public agencies, and by the affected industries. Wherever conducted, however, this basic function of extending the frontiers of knowledge and application in this field requires and merits continuing and vigorous stimulation by the Federal Government.

5. *Continuous planning.*—A widening interest and responsibility on the part of the Federal Government for the wise conservation and utilization of the Nation's energy resources raises many perplexing questions of policy determination. In essence, there must be continuous adequate planning and provision for studies which will reflect the best technical experience available as well as full consideration for both regional and group interests.

Better to provide for continuous planning and studies of policies, we recommend the organization of an advisory planning group for the energy resources. This group, however, should comprise only one unit in an over-all planning agency specifically established within the Federal Government to serve the President and the Congress in an advisory capacity on planning and policy matters for all our national resources. Members of such an energy resources planning group should include representatives from the Federal and State agencies concerned, from the industries, and outside experts. The organization of such an advisory planning group would not mean the abolishing of the planning functions now carried on by existing agencies. To the contrary, planning in existing agencies would have to be encouraged and strengthened; for without it the over-all planning group would be left without background, experience, and technical assistance.

Conclusion

We have pointed out earlier in this statement that it is now time to take a larger view: to recognize that each of our great natural resources of energy affects the others. Bituminous coal, petroleum, natural gas, anthracite coal, and water power—in descending order of relative contribution to the Nation's energy supply—these are the energy foundations of our industrial civilization. A policy for any one of these resources is bound to affect its relative position with respect to the others.

It is difficult in the long run, therefore, to envisage a national coal policy or a national petroleum policy or a national water-power policy without also in time a national policy directed toward all these energy producers—that is, a national energy resources policy. Such a broader and integrated policy toward the problems of coal, petroleum, natural gas, and water power cannot be evolved overnight, for each of those problems is amazingly complex and in combination they represent more than a simple sum of problems.

Despite the complexity of those problems, in the national interest we shall have to move in the direction of solutions. It is well to remember that the present and proposed regulatory measures which we have discussed are designed to promote the development of the energy resources industries along lines that will be consistent with the broad national interest. The problems of conservation which dictate these measures are not the result of passing emergencies. Rather, they are continuing problems, and if they cannot be solved by the regulatory approach then we may anticipate with some confidence that there will emerge an insistent and eventually irresistible demand for public ownership and control.

The paramount responsibility of Government is to protect the general welfare. That way lies safety and a progressive evolution of our economy and of our political institutions. No amount of confusing legalistic discussion of limitation of powers can obscure the reality of the choices before us. To protect the general welfare in our time—in an industrialized and urban economy—means, above all else, to build and maintain in good order a sound economic structure. In an industrial civilization the energy resources constitute the foundation of that structure.

The broadening of the Federal interest with respect to these energy resources has been justified primarily on the basis of the need for their conservation, broadly defined to mean their wise use. But it must be observed that the need for conservation is but a special case. The general case is that Government intervenes with control measures when the economic organization of a segment of the economy is such as not to yield socially desirable results. If the economic organization is one of monopoly, "natural" or contrived, Government intervenes to restrain the exercise of the privileges of monopoly; e. g., rate regulation or yardstick regulation of electric utilities. If the economic organization is such that competitive conditions and practices produce chronic depression in the industry and demoralizing distress among those dependent on the industry, then Government intervenes to seek correction of those conditions and practices; e. g., regulation of the bituminous coal industry. If the economic organization is such as to result in grave waste of irreplaceable and distinctly limited resources, then Government may and should intervene to protect the public interest in conserving the supplies of those resources; e. g., the case for the determination and enforcement of minimum Federal standards in the production and transportation of petroleum and natural gas.

It is not likely that backward steps will be taken; it is not likely that we shall retreat from the social and economic advances made in the domain of the energy resources. Rather, it is likely that we shall press on toward the objective of the general welfare.

LETTER FROM THE PRESIDENT

THE WHITE HOUSE
WASHINGTON

March 15, 1938.

Hon. HAROLD L. ICKES,
Chairman, National Resources Committee,
Washington, D. C.

MY DEAR MR. SECRETARY:

The need for a comprehensive study of our energy sources, their prudent utilization and conservation, and their competitive relation to each other and to the national economic structure becomes increasingly evident. I know that much basic material has been gathered by various branches of the Government and that studies of various aspects of this broad subject are continuously being made by these agencies.

However, I believe that the subject is important enough to warrant particular attention with a view to concentrating the available data, and presenting the outlines of a program.

Accordingly, I am requesting the National Resources Committee, in consultation with all other interested agencies of the Government, for example, on water power problems with the Federal Power Commission, on oil and gas problems with the Petroleum Conservation Division, and on coal problems with the Bituminous Coal Commission, to undertake this task with a view to letting me have a report with findings and recommendations at the earliest time, but certainly before the next regular session of Congress.

Sincerely yours,

FRANKLIN D. ROOSEVELT.

LETTER FROM THE ENERGY RESOURCES COMMITTEE

National Resources Committee
Interior Building
Washington

January 19, 1939.

Hon. Frederic A. Delano,
Chairman, Advisory Committee,
National Resources Committee.

Dear Mr. Delano:

We have the honor to transmit herewith a report on "Energy Resources and National Policy" prepared in accordance with the request of the President to the National Resources Committee on March 15, 1938.

In compliance with the letter and the spirit of the President's request, the Federal bureaus and agencies concerned, as well as several selected State agencies and private organizations and institutions, have been consulted and have submitted voluminous basic data and analyses necessary in the consideration of this complex problem. These data have been digested and summarized and suggestions on policies prepared by Dr. Ralph J. Watkins, assisted by a research staff especially organized for the purpose.

The report as submitted, therefore, consists of two parts:

(*a*) A summary, including discussions of policies.

(*b*) Supporting data and detailed analyses by specialists both within and outside the Federal Government.

Representatives of the interested Federal agencies that have supplied the factual material and analyses have also been given opportunity to review the summary and have made suggestions which have been incorporated in the report.

The findings and recommendations which we endorse in principle have been summarized and are contained in the opening statement of the report. Naturally, this endorsement is personal and is not to be construed as an official expression of the views of the agencies with which we are connected. We urge that adequate provision be made for a continuing review of the recommendations for policies contained therein, particularly in view of the additional investigations which will be made and of the growing emphasis upon the wise conservation and prudent utilization of the Nation's energy resources.

Respectfully yours,

Ralph J. Watkins, *Chairman.*

F. A. Daubin.
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John W. Frey.

Roger B. McWhorter.
W. C. Mendenhall.
H. K. Rutherford.
F. G. Tryon.

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ENERGY RESOURCES AND NATIONAL POLICY—A SUMMARY

In our industrial civilization machinery and power are key words, for the machines which characterize our society are power-driven machines. The motive force on which we have relied to turn the wheels of these machines—as well as the fuel for essential heating and for the processes of industry—has come largely from exhaustible resources. Fortunately, we have coal, oil, and natural gas in relative abundance, but this abundance cannot last indefinitely. These resources were millions of years in the making, and every ton of coal used, every barrel of oil used, and every cubic foot of natural gas used is so much wealth drawn from nature's storehouse. Water power, fortunately, lies in a different category, since to use it is to conserve it. But neither the magnitude nor the geographic pattern of our industrial life has been determined by falling waters.

This report is concerned with the prudent utilization and conservation of these energy resources.

I. The Broader View

Coal, oil, natural gas, and water power are the principal sources from which we have obtained the energy for the heat, light, and power essential to a growing industrial civilization. Particularly in recent years the conservation of these great natural resources, their orderly development, their readiness in case of need for the national defense, and the preservation in economic health of the industries that make them available have become matters of national concern. We have realized that the abundance provided for our use by nature will not last forever. We are beginning to realize that the welfare of millions of our people is bound up in these great industries.

Important legislative and administrative measures have been undertaken in these directions with varying degrees of success. In general, each of these efforts has been directed toward the problems of a single field; toward the protection of the public interest in the power of flowing water in the Nation's rivers; toward the relief of economic and human distress and the lessening of waste in the mining of coal; or toward the correction of demoralizing and wasteful practices and conditions in the industries producing oil and natural gas. It is time, however, to take a larger view, to recognize more fully than has been possible in the past that each of these energy resources affects the others, either directly through competition for markets or indirectly through the profound importance of energy in the whole pattern of our industrial and commercial life.

It is important to note here that the development of these resources is already far advanced and will continue. The question is not one of promoting or failing to promote the exploitation of our energy resources. The question is whether the Nation shall permit this exploitation to continue without adequate regard for waste, for social objectives, and for future welfare—or shall endeavor to guide it into ways that are more effective for both economic and social objectives than it has followed in the past. Moreover, consideration must be given to the interlocking relationships among the energy resources, to the growth of energy requirements with respect to the most advantageous sources of supply for present and future needs in various sections of the Nation, to the vital importance of power and the liquid fuels in support of the national defense, and to the orderly scheduling of the development of fuel and water-power resources in each region for the greatest economic and social benefit.

II. Sources of Energy [1]

The total consumption of energy in the United States is enormous, proportionately far more than that of any other nation. It has been estimated that our consumption of power per capita is 50 percent higher than that of Great Britain, more than twice that of Germany, more than 10 times that of Japan, and 150 times that of China. Heat for homes, buildings, blast furnaces, and smelters; light, indoors and on the streets and highways; power in coal, gasoline, and fuel oil for locomotives and motors in transportation by land, air, and water; power for every purpose from the threshing machine to the great turbines that drive electric generators—such needs for energy in 1937 represented for each family in the country the equivalent of the work of 120 theoretical horses working 8 hours a day 6 days a week for the entire year. Industries of more than local significance supplied most of this energy in the form of coal, oil, or natural gas or in the form of electricity derived from one of these mineral fuels or from water power.

The total amount of energy used each year increased six-fold in the 40 years 1889 to 1929, and for 1937 the high figure of 1929 was nearly equalled. In 1937 bituminous coal supplied 48 percent of the total amount of energy derived in the United States from mineral fuels and water power for all purposes; Pennsylvania anthracite supplied 6 percent; petroleum, 32 percent; natural gas, 10 percent; and water power, less than 4 percent. These figures relate to the total supply of energy for all purposes, including that used as heat. In the generation of electric power for public use, water power constitutes a much larger proportion—36 percent in 1937.

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[1] For supporting evidence and detailed analysis, see the following sections of the accompanying report: Pt. I, sec. I: The Coal Industry; pt. I, sec. II: The Petroleum and Natural Gas Industries; pt. I, sec. III: Potential Water Power in the United States; pt. II, sec. I: Fuel Reserves; pt. II, sec. II: Water Power Resources; pt. II, sec. III: Substitute Fuels and Marginal Energy Resources.

Almost 90 percent of the bituminous coal came from eight States: West Virginia, 26.7 percent; Pennsylvania, 24.9 percent; Illinois, 11.6 percent; Kentucky, 10.6 percent; Ohio, 5.5 percent; Indiana, 3.9 percent; Virginia, 3.1 percent; and Alabama, 2.8 percent. Nearly all the anthracite was mined in Pennsylvania. The States of Texas, California, and Oklahoma accounted for more than three-fourth of the production of petroleum, Texas alone accounting for 40 percent; Louisiana, Kansas, New Mexico, Pennsylvania, Illinois, Michigan, and Arkansas contributed most of the remainder. Texas, California, Louisiana, Oklahoma, and West Virginia produced most of the natural gas. Water power production was distributed over wide sections of the country but was largest in the Pacific States, the Middle Atlantic States, and the South Atlantic States.

Bituminous coal and anthracite have lost ground relatively since about 1904, although the actual quantities mined continued to increase steadily until 1918. Since that year the relative loss has been accelerated. Actual consumption of anthracite has shown a downward trend since 1923 and that of bituminous since 1929, although in both cases the record in recent years has been obscured by the great depression. The fact that the use of coal has shown a declining tendency is a matter of serious concern, because it has meant depressed conditions in the coal industry and a heavier drain on the less plentiful resources. It may be attributed to many causes, but especially to the competition of oil and gas and to the greatly increased efficiency in the use of coal.

With the coming of motor transportation the production of petroleum began a rapid advance to supply the great new need for gasoline and lubricating oil. This advance apparently is still in progress, partly at the expense of coal through the substitution of oil for coal as a fuel for heating and partly through displacement of railroad transportation by motor transportation. Natural gas has followed the growth of oil, owing in some degree to their association in production but accelerated greatly by the remarkable development of long distance pipe lines.

The power of falling water in the streams has been developed at such times and places as justified hope of profit. Before the introduction of coal, whole industries grew up around the water wheels of New England, New York, and Pennsylvania and along the Fall Line southward. The production of water power has closely followed the total consumption of energy, increasing manyfold but maintaining about the same relative position. Water power is unique as a source of energy in that it is not reduced by use, but is wasted if not used. We may continue to enjoy the power of falling water in the Nation's streams as long as nature's processes continue to function as they do at present. Coal, oil, and gas, on the other hand, must be considered irreplaceable national assets. This uniqueness, together with the circumstance that power is only one of the vital uses of water, endows water power with a special public interest. Dams and other structures that make the power available will affect other uses of the water and the stream. Power, therefore, must be considered with respect to other uses of water and, conversely, other uses must be considered with respect to power.

The potential importance of energy resources in the economic development of the several sections of the country will be apparent. No less significant is the influence that the location of these resources may have on future trends in population, industry, and commerce.

III. Electric Energy [2]

The significance that attaches to the production of electricity for public use arises from its direct effect on nearly all the people and on most of the industry and commerce of the country. The electric utility industry operates for economy in relatively large units. Both private and public systems have been financed by the public sale of securities. The industry is a public necessity and a convenience to nearly everyone; it is virtually a monopoly in most places and to most of its customers and for low costs and efficiency should be so. For these reasons, efforts to control the exercise of the special privileges granted to this industry by the public have been the subject of legislation since its inception. The industry is one of recent and rapid growth. Production of electricity for public use in 1937 was more than one-fourth higher than in 1929 and almost three times that in 1920.

Of the 1937 production of electricity for public use, 36.1 percent was derived from water power; 51.3 percent from coal, mainly bituminous; 7.8 percent from natural gas; and 4.4 percent from oil, with a very small amount from waste fuels such as sawmill refuse. Use of fuel for generating electric energy represented only a small fraction of the total market for coal, oil, and natural gas; but most of the water power output was used for this purpose. The proportion of electric energy for public use derived from water power has ranged from 32 to 40 percent since 1920. The proportion derived from natural gas and oil has increased at the expense of the proportion derived from coal, although the actual amount of electric energy generated from coal for public use has steadily increased and in 1937 was more than twice what it was in 1920. Here we have a striking example of the loss of coal markets through greater efficiency in use. The production of electricity from coal more than doubled from 1920 to 1937—indeed, from 1920 to 1929—yet the consumption of coal for this purpose remained about the same. In other words, the electric industry obtained from every pound of coal more than twice as much electricity in 1937 as it did in 1920. At the 1920 rate 50 million tons more coal would have been consumed in 1937, or more than one-tenth of all the coal mined in the United States in that year. Other industries, and especially the larger industries consuming coal, have also improved their efficiencies, although in less degree.

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[2] For supporting evidence and detailed analysis, see the following sections of the accompanying report: Pt. I, sec. III: Potential Water Power in the United States; pt. II, sec. II: Water Power Resources.

Geographically, the production of electricity follows closely the distribution of population and industrial and commercial activity in the United States, as would be expected from its intimate relationship to the people and their economic life. The geographical distribution of water-power production is a matter of considerable significance. In the Middle Atlantic and East North Central States only one-fifth of the total production of electric energy for public use in 1937 was generated by water power. In New England water power production was two-fifths of the total; in the South Atlantic States, one-half; in the Mountain States, three-quarters; in the Pacific States, six-sevenths.

IV. The Problem of Conservation [3]

The terms "conservation" and "prudent utilization" connote a present or threatened inadequacy of some of or all the energy resources. Analysis of the field of the threat—fortunately not a present inadequacy—points to oil, natural gas, and the higher grade coals. A few figures bear out that statement. Our coal reserves have been estimated at somewhat more than 3,000 billion net tons, more than half of the total reserve being represented by low-grade bituminous coal and lignite. Expressed in terms of equivalent high-grade bituminous coal, these reserves represent about 2,500 billion net tons. But the high-grade, low sulphur coals best suited to the manufacture of coke are severely limited. Petroleum in proven natural reservoirs, according to current estimates, amounts to approximately 4 billion net tons of equivalent bituminous coal, and currently estimated proven natural gas reserves to approximately 3 or 4 billion net tons of equivalent bituminous coal. Even oil shale, which in comparison with oil in natural reservoirs is relatively abundant, amounts to only about 21 billion net tons of equivalent bituminous coal. It can be seen readily from a comparison of these figures where the emphasis must be placed in a program of conservation. At this point let it be said that conservation of energy resources does not mean abstinence from use, or hoarding; rather, it means wise use; that is, the efficient use of our energy resources in the interest of the national welfare, the avoidance of unnecessary waste in their production and utilization, and the safeguarding in economic health of the industries and populations on which we rely for the development of these vital energy resources.

It is a commonplace to say that our position with respect to energy resources is a fortunate one, that nature has been bountiful in her endowments of our domain. Despite our relatively fortunate position, however, it may be said that our resources are sufficiently limited to make the avoidance of unnecessary waste a matter of serious concern to the Nation. Although our total coal reserves have been estimated at approximately 3,000 billion net tons (in comparison with 1929 production of slightly more than 600 million net tons and total production to date of about 23 billion net tons), more than half of this total is represented by low-grade bituminous coal and lignite. Almost 70 percent of the total reserve lies in the semiarid plains or in the Rocky Mountains, far from centers of population and industry; and about 85 percent of present production is from the 30 percent of the reserves east of the Mississippi River. Pennsylvania anthracite is more than one-fourth exhausted, and some of the finest bituminous seams would be exhausted in from one to three generations at the 1929 production rate. Avoidable wastes in bituminous coal mining were estimated by the United States Coal Commission in 1923 at almost 20 percent of the beds mined. Progress since that time, because of depressed conditions in the industry, appears to be slight, if not actually negative. Our problem with respect to coal is not total exhaustion even in the fairly remote future but rather a relatively early increase in cost because of the depletion of the richer and more accessible deposits. There is, moreover, a serious problem of economic under-utilization, weighted with grave social implications for the hundreds of thousands who now depend on coal for a livelihood, a problem more pressing than the necessity for conservation but on the solution of which conservation methods are dependent.

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[3] For supporting evidence and detailed analysis, see the following sections of the accompanying report: Pt. I, sec. I: The Coal Industry; pt. I, sec. II: The Petroleum and Natural Gas Industries; pt. I, sec. III: Potential Water Power in the United States; pt. II, sec. I: Fuel Reserves; pt. II, sec. II: Water Power Resources; pt. II sec. III: Substitute Fuels and Marginal Energy Resources; pt. III, sec. I: Coal Mining Wastes and Their Prevention; pt. III, sec. II: Phases of Technology in the Petroleum Industry; pt. III, sec. III: Conservation in Use; pt. IV, sec. I: The Conservation Movement with Special Reference to the Mineral Fuels.

Reserves of oil and gas present a different picture. Proven oil reserves have been estimated as of January 1, 1938, at 15 billion barrels, in comparison with 1937 consumption of about 1¼ billion barrels. Discovery, however, has within recent years more than kept pace with production, and the techniques of exploration and discovery, of extraction, and of refining are changing and improving rapidly. Nevertheless, according to our present-day knowledge, oil must be regarded as a distinctly limited resource. Even if our reserves should last a century, we may face a shortage with consequent higher prices within a decade or two. The dependence of our civilization on low-cost liquid fuels and lubricants is so great that we simply cannot afford not to concern ourselves with the prudent utilization of this resource. Recent estimates place our proven natural-gas reserves at from 60 to 100 trillion cubic feet, in comparison with annual consumption of somewhat more than 2 trillion cubic feet. Here again, discovery has outdistanced consumption, but the resource is a limited one and prudence dictates wise use.

With a great industry engaged in the extraction and refining of petroleum, with other industries based largely on low-cost liquid fuel, and with the far-reaching potential effects of further expansion of oil and gas into new fields of application, it is certainly the part of wisdom to proceed cautiously in the use of these distinctly limited resources. We are depleting our reserves of oil faster than the rest of the world. We must consider the possibility of being first among the oil-producing nations to feel the pinch. We must consider whether to use more wisely our available supply or to manufacture high-cost substitutes or to depend—with obvious hazards—on foreign oil for our motor cars and airplanes, our tractors, and our battleships.

After our natural reservoir oil is exhausted or after the shortage becomes serious, we can turn to oil made from coal, to oil shale, or—to a limited extent—to alcohol from vegetable matter, but at much higher costs. Although no alarm need be felt over the possible breakdown of a motorized civilization, we may well be concerned over the higher costs that we would have to pay and at the prospect of handicaps in international competition. Any extensive use of the tides, the winds, the temperature differentials in the earth and in deep waters, solar radiation, and atomic energy would involve such high costs by present-known methods that these sources of energy must be considered as very remote.

Water power as an energy resource that renews itself is in sharp contrast to the fuels. Undeveloped water-power sites capable of producing about six times as much energy as those now developed, or more than twice the total production of electricity for public use in 1937 by fuel and water power combined, have been listed by the Federal Power Commission as being economically feasible when a market for their output exists. At best, however, water power can never supply a major part of our energy requirements. It has been estimated, for example, that all our water power, including both that already developed and that feasible of development, could produce energy annually equivalent to only about one-fourth of the energy contained in all mineral fuels consumed in the country in 1937 for all purposes.

Nature distributed these water-power resources without regard for our present population and its requirements. The relation between feasible undeveloped water power and present power consumption ranges widely. For example, the Pacific Northwest (Oregon, Washington, Idaho) contains nearly half of all the Nation's undeveloped water power; the potential output is more than 20 times the 1937 production of electricity for public use in those three States. In the Pacific Southwest (California), Nevada, Utah, Arizona) the ratio of undeveloped water power to 1937 production for public use is 5 to 1; in the Mountain and Plains States (Montana, Wyoming, Colorado, North Dakota, South Dakota, Nebraska, Kansas), 3½ to 1; in the Southeast (Virginia, North Carolina, South Carolina, Georgia, Florida, Kentucky, Tennessee, Alabama, Mississippi), 2½ to 1. There is not enough potential and feasible water power within present economical transmission distance of the larger industrial and urban areas in the eastern half of the country to supply their present needs for electric energy without the aid of fuel. It is clear that power requirements of the relatively near future will make necessary in most regions new supplies of energy exceeding the capacity of all the available and feasible water-power sites.

V. Fields of Remedy [4]

From the evidence reviewed in this study, it appears beyond argument that the Nation's patrimony in energy resources should be safeguarded, that a sound national policy should be concerned with the prudent utilization and conservation of these resources. The obvious fields of remedy with respect to conservation of energy resources seem to lie (1) in promoting greater efficiency in the production of mineral fuels from the standpoint of recovery; (2) in promoting greater economy in the use of fuels; and (3) in placing a larger share of the energy burden on lower grade fuels and water power.

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The problem of preventing waste in the fuel industries is primarily an economic one. An industry which is harassed by chaotic conditions of competition can hardly be expected to develop a broad and socially constructive program of conservation. Thus, Federal attempts at aiding in solution of the problems of these industries have represented measures designed to eliminate uneconomic practices or to mitigate some of the consequences of unfettered competition. It is essential, however, that the aim of conservation be not lost sight of in such programs.

Fortunately, the aim of increasing the efficiency of utilization is furthered by the profit motive. The consumer of fuel finds it very much to his interest to make his purchases go farther. In consequence, much progress has been made; and the policy problem in encouraging this type of conservation is not so serious, although it is present in many uses of fuel.

The quantity of water power is in a significant sense dependent on public policy, in the sense that economic appropriation of much of the potential power depends on storage and controlled release of water. For the larger basins, an integrated policy of storage and use seems not within the scope of private enterprise, nor within State or municipal scope without Federal cooperation. Thus, the amount of practically available water power is very much dependent on the extent of Federal development. Federal stream and basin developments naturally must be considered from many angles besides that of promoting the use of a replenishable resource. The prudence of that aim, however, would seem to be soundly supported.

The problem of promoting the use of lower-grade fuels is essentially a problem in research; that is, in promoting research into methods of utilization of those more plentiful fuels not now being drawn upon.

VI. The Function of Research in a Conservation Program [5]

The production and the use of mineral fuels are accompanied by large wastes of the most valuable energy resources of the Nation. This waste may be traced to economic barriers opposing the application of known methods of conservation, economic barriers related to the existence of exceptionally large and accessible deposits of the higher-grade fuels—natural gas, petroleum, and coal. The supplies of these fuels can be protected from unnecessary depletion by research (1) to promote greater efficiency in production from the standpoint of the percentage of recovery, (2) to promote greater economy in use, and (3) to fill a larger part of the demand for energy by the use of lower grade fuels.

The history of petroleum and natural gas production has been marked with special evidence of waste—particularly that of natural gas associated with oil. Increased technical knowledge has shown that the waste of gas invariably means a reduction of the quantity of oil recovered as well as reduction of the quantity of gas that can be sold, but much remains to be done in correlating data pertaining to better utilization of gas energy, recycling of gas to recover more oil, storage of excess gas in partly depleted fields, and improvement of conditions that affect transportation of gas to market.

The fact that 80 to 90 percent of the oil has been left in the ground in many of the older fields calls for every reasonable effort to avoid premature abandonment of reservoirs. Present-day operations conducted in accordance with the best known practices probably leave 50 to 60 percent of the original oil, and some fields may yield 70 percent or more of their liquid content. There is reasonable basis to believe that another decade of research and practical application of scientific findings will show today's best methods of promoting greater efficiency in production from the standpoint of percentage of recovery as having been inefficient and "wasteful."

An increasing proportion of oil is being produced from deep-lying reservoir rocks. The attending high pressures and temperatures call for new techniques, and these are being developed rapidly. Operations to an increasing degree must be based upon accurate knowledge of flow characteristics, composition, and phase relations of reservoir fluids in their travel upward to the surface.

Although refining of petroleum may be regarded as being highly efficient, yet industrial research is constantly providing improved methods. In the early history of the industry the principal products were kerosene and lubricants, but with the growth of automotive transportation the demand for motor fuel caused a change in refinery technique. Gasoline became the principal product, and it was accompanied by an increased production of fuel oil which also found a ready market. It is possible that in the future, when the supply of petroleum diminishes and substitute motor fuels have been developed, lubricants will assume a more important position among the products obtained from petroleum. Refineries today are producing from crude oil charged to stills a yield of 44 percent gasoline, 39 percent fuel oils, and 3 percent lubricants. Processes are available, however, that can produce 80 percent gasoline and have wide latitude for adjustment to meet changing demands by producing larger proportions of other fractions.

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Careful surveys have shown that in the underground mining of coal 35 percent of the original deposit is left underground and lost. More than half of this loss could be avoided with reasonable effort. Costs of mining are lowest in beds from 5 to 7 feet thick. In thinner or thicker beds the costs are higher and therefore only the most accessible coal is taken; consequently, the avoidable losses are increased. In many mines the roof or floor is bad, and part of the coal is left in place as the cheapest way to maintain safe working conditions. A third important factor is the cost of removing pillars, the cost of recovery of coal in pillars frequently being more than can be realized from the sale of the coal. Research in mining methods may result in the design of systems of mining the thick and thin beds that will give high extraction with low costs; methods of control of roof and floor may be developed that will make it unprofitable to leave coal in place; and further study of the properties of overlying strata may eliminate excessive losses in pillars.

Mechanical mining has developed rapidly, and machines can cut and load at a high rate the most accesible coal in a deposit, but in order to keep costly machines constantly employed and to safeguard against damage to them, much coal is left behind. Thorough study of the problems of mechanical mining undoubtedly will indicate methods by which losses may be reduced.

Mechanical mining, and particularly the use of loading machines, eliminates sorting the coal in the mine and requires an efficient mechanical cleaning plant on the surface if the impurities in the coal are to be removed. The modern cleaning plant developed by industry has greatly reduced losses of coal through discarding uncrushed lumps containing both impurities and good coal. The mechanical plant crushes these lumps, liberates and saves the good coal, and rejects the impurities. Continued research in methods of coal cleaning will result in further elimination of ash and sulphur, the two principal impurities in coal.

Mining by stripping of overburden is an important factor. By this method beds that cannot be mined economically by underground methods become available, and the recovery is high—usually greater than 90 percent. But this gain is offset in some areas by the resulting destruction of soil resources or by the marring of the landscape. Public objections to this method of mining may be overcome by research to develop low-cost methods for reclaiming for agricultural or other use the unsightly areas left behind.

In addition to losses in the production of the mineral fuels there are varying degrees of loss owing to inefficient utilization. Large-scale use of petroleum and natural gas is a comparatively recent development, yet research by industry has developed appliances—burners, furnaces, and gasoline and Diesel engines—in which they are burned efficiently; and there is ample reason to expect further research to lead to greater efficiency, that is, more miles per gallon of gasoline in automobiles and more useful heat per pound of fuel burned in furnaces, hence less fuel used. This conservation will result from improved qualities in the prepared fuels as well as from improvements in methods of utilization.

Perhaps the most accurate measure of improvement of economy in the use of fuel is given by the records of the generation of power from coal by the public utilities. Definite figures are available that show a decrease in the average consumption of coal by public utility power plants from 7.05 pounds per kilowatt-hour in 1899 to 3.2 pounds in 1919 and to 1.42 pounds in 1937. The most efficient modern stations are producing a kilowatt-hour from 0.8 pound of coal. Boiler efficiencies have been raised from 60 and 70 percent to 90 and 92 percent.

In the last two decades research has led to the development of pulverized-fuel burning equipment with its peculiar suitability and effectiveness for the larger installations, the spreader stoker with its ability to handle a wide variety of coals, the enlargement of the underfeed stoker, the small domestic stoker, the highly efficient and specially designed oil and gas burners, the improved automobile and Diesel engines. Research by industry has made these advances possible. Research was and still is necessary to obtain information on the chemical and physical characteristics of coal, on its coking properties, on the mechanism of combustion, carbonization, and gasification, on the fusibility and clinkering properties of the ash, on the effect of size on the use of coal, and on treatment to allay the dust in coal used for domestic purposes.

Naturally the fuels that are easiest to obtain and most convenient to use are being depleted most rapidly, leaving for future generations the fuels more difficult of access, less suited to the uses for which they are required on the basis of present-day values, or lacking in the convenience that gives them form value. It is evident that substitutes for these fuels must compete on the basis of convenience as well as of initial cost.

The Diesel engine promises better fuel utilization than the gasoline engine. Diesel engines not only afford more miles of travel per gallon of fuel, but also they probably will be developed to use fuel similar to much of the raw material of gasoline manufacture. Research is necessary to reduce the present high cost of building Diesel engines and to develop them so that they will perform as smoothly as gasoline engines. Improvements are to be expected, and progress already has been made in the use of Diesel engines in heavy trucks, where cold starting, quick acceleration, and other items of performance are not so important to the user as lower cost of fuel.

In certain industries employing fuel-burning equipment, pulverized coal, and frequently coal of low rank, is used in place of liquid or gaseous fuels. Thus pulverized coal is used in cement kilns, metallurgical furnaces, and under steam-generating boilers.

In the burning of raw coal for the production of heat several outstanding developments have made possible the substitution of lower grade coals. The spreader stoker, first developed for small boilers (100 horsepower) and now extending to larger boilers of 2,000 to 3,000 horsepower, has in the past 10 years brought about the use of a large quantity of the small size, or slack, low-grade coal of high ash content and low ash-fusion temperature; the introduction of the slagging type of pulverized fuel furnace has made possible the use of much coal with lower ash-fusion temperature; the development of water-cooled grates for stokers also is extending the use of low-grade coals. The small domestic stoker with automatic control, movement of coal directly from the bin to the stoker, removal of the ash to the outside of the house, together with the allaying of coal dust, is enabling coal to regain its place in house heating.

Much research has yet to be done both by industry and by public and quasi-public agencies to accomplish further advances. This includes studies on the sizing of coal, the properties of different sizes having a direct bearing on burning characteristics; on the ignitability and reactivity of coal burning in the raw state; on coking, agglutinating, and swelling properties; on the nature of the volatile matter; on the ash and its fusing and slag-forming characteristics: on many details in connection with the control and operation as well as the design of virtually all coal-burning equipment. Much improvement has yet to be made in the over-all efficiency of steam locomotives.

Research can serve not only the immediate desire for economy, but can serve also the future by devising methods by which inaccessible fuels are made accessible, methods whereby fuels are enabled to serve in uses in which they previously were not serviceable, and methods of conversion whereby products of the lower-grade fuels can serve with equal convenience in place of the fuels having greater form value. Thus, research can extend the reserves of petroleum and natural gas, can develop methods for making gasoline and lubricants from coal, can decrease the cost of making gas from coal, can originate uses for byproducts whereby their value will be increased so that they can bear a larger part of the burden of the cost of coke making and thereby make a smokeless and convenient fuel widely available, can make coke of coals that could not well be used in earlier coking processes, can develop methods of recovering most of the coal from thin and thick beds, and can, in an unpredictable number of other ways, bring about changes that will conserve the Nation's fuel resources and will retard the inevitable depletion of the fuels at present considered to be most valuable.

Both fundamental and applied or industrial research is needed in the conservation of the national fuel reserves. Fundamental research is required to apply the constantly increasing stream of new knowledge in the fields of chemistry, physics, and geology toward obtaining a better understanding of the occurrence, composition, properties, and changes which the mineral fuels undergo in their winning, preparation, and utilization. Such research applied to geophysical prospecting has resulted in the discovery of many new reservoirs of petroleum at lower costs; the application of physical-chemistry to petroleum refining has greatly increased the yields and improved the quality and efficiency of utilization of motor fuel and lubricants from petroleum; studies on the mechanism of combustion of solid fuels are fundamental to the continual lowering of the pounds of coal required for the generation of a kilowatt of electrical energy in power stations.

Fundamental research is conducted principally by educational, governmental, and institutional agencies, although some of the larger industrial corporations also have made and are making important contributions, especially in the petroleum industry.

Industrial research is required to apply the results of fundamental research to the immediate problems of industry in winning, preparing, and utilizing fuels. Machinery and equipment must be developed to carry out on an industrial scale new reactions that have been discovered by the scientists, as, for example, the making of a high antiknock motor fuel from waste refinery gases or volatile hydrocarbons, heretofore wasted, in the recovery of gasoline from natural gas; stokers and furnaces must be devised to fit the plastic and caking properties which fundamental investigations have disclosed with respect to the different kinds of coal.

In general, applied research on the preparation and utilization of fuels is conducted by industry under the stimulus of the profit motive; and, therefore conservation in utilization has made much greater progress than conservation in mining coal or winning petroleum or natural gas. Research along these lines and in the substitution of lower grade fuels for the more limited resources of petroleum, natural gas, and the higher grade coals is less likely to be conducted by industrial interests. This type of applied research, as well as much of the required fundamental research, needs the support of governmental agencies.

It will be recognized at once from what has been said in this section that the research function is a basic part of a program of conservation. It follows, therefore, that the Federal Government should actively and generously support this work in all its agencies concerned with the energy resources and that this work should be vigorously pointed in the direction of conservation.

The business of the Federal Government is much more far-reaching and much more complex than any other business in our country. It follows that if Government is to be efficient there must exist within the Government establishment the soundest possible basis for meeting and solving the problems that arise in this complex business. This, in turn, means that the personnel of Government must include authorities in each of the fields of human activity—men and women who are devoting their lives to some field of special knowledge and who, in the aggregate, cover essentially all fields and whose special training and special knowledge are at all times available.

National policies must be formulated, and those policies are only as sound as the foundation of fact and deduction upon which they rest and then only to the extent that this foundation is utilized. Most well-conceived Governmental action, if traced back to its source, will be found to spring from the work of one or many research workers, distributed among the Government offices and laboratories. They must supply the answers which are the tools and the materials used in the formulation of sound policies. To be prepared to supply the answers to the complex questions that will be asked during the next year or the next decade, research workers must be continually engaged in advancing the frontiers of knowledge. This is research. It is essential throughout the Government and nowhere more so than in those agencies on whose work a program of conservation of energy resources must be based.

VII. Public Policy Toward the Coal Industry[6]

The coal industry of the United States has been in a continuous depression since 1923. This depression has been more acute in the anthracite than in the bituminous coal industry in recent years. As the deposits of anthracite are virtually confined to Pennsylvania, the difficulties of anthracite have commonly been thought of as a State rather than as a national problem. This view may prove short-sighted, but thus far experience in Federal regulation—except for the period of the World War—has concerned only the bituminous industry. The following discussion, therefore, will be limited to bituminous coal.

The problems of the bituminous industry are not new. They go back to the sheer abundance of the underground reserves. Application of the common-law doctrine that surface ownership carries title to the underlying mineral, which the colonists brought from Stuart England to the New World, resulted in scattering ownership of the resources among some millions of land owners. Adoption in 1906 of the policy of withdrawing the coal lands still remaining on the public domain from further entry and the passage in 1920 of the Mineral Leasing Act came after virtually all of the more accessible deposits had already passed into private control. Much of the more valuable coal has been sold by the original holders to mining or royalty companies, but title to workable seams remains scattered among scores of thousands of owners, each of whom naturally desires to realize upon his property by sale or by development.

This condition early led to the opening of great numbers of mines with a capacity far in excess of the national requirements. A surplus of capacity is revealed by the first census which gives an intelligible picture—that of 1880. Thereafter, capacity continued to expand, always outstripping requirements, and in the 25 years immediately preceding the World War, the bituminous mines of the country operated on the average only 213 days a year. The surplus of capacity and the division of the industry into many thousand units scattered over 32 States produced a condition of cutthroat competition. The demand for coal is inelastic. While a shortage caused by a strike or a lack of railroad cars may cause a violent increase in price, the offering of even a small tonnage beyond immediate requirements has a peculiarly depressing effect on price. The pre-war surplus of capacity led to a chronic tendency to overproduction.

The pressure on prices was, in turn, reflected in severe pressure upon labor standards. Wages constituted more than 60 percent of the cost of production, a proportion higher than in any other large industry, and the operator found that in the absence of agreement on a standard wage, he was compelled to cut the rate. To maintain wages, collective bargaining was therefore seen to be necessary, and the intensity of interstate competition required that it be on an industry basis. Attempts at interstate wage agreements began in the eighties, broke down completely during the depression of the nineties, and were revived in 1898. Great areas of the industry, however, remained nonunion; advances in standards were slow; and labor relations in the industry, throughout the pre-war years, remained fundamentally unstable. Violent struggles occurred over the organization of the non-union fields. The Paint Creek-Cabin Creek strike of 1913 and the Ludlow, Colo., strike of 1914 led to bloodshed and Federal investigation. Competition of non-union coal produced at lower wages made it difficult to maintain a reasonable scale, and the expiration of the 2-year agreements in the union fields was nearly always accompanied by a deadlock over the terms of renewal. Suspensions of mining occurred in 1904, 1906, 1908, 1910, 1912, and 1914, that of 1906, for example, involving 211,304 men in 10 States, who were idle 63 working days.

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[6] For supporting evidence and detailed analysis, see the following sections of the accompanying report: Pt. I, sec. I: The Coal Industry; pt. II, sec. I: Fuel Reserves, (1) Coal; pt. III, sec. I: Coal Mining Wastes and Their Prevention; pt. IV, sec. I: The Conservation Movement with Special Reference to the Mineral Fuels; pt. IV, sec. IV: Regulatory Measures in the Coal Industry.

In the meantime, coal operators, though continuing to expand their business, found their position financially unstable. In Illinois between 1913 and 1915, companies responsible for 25 percent of the State's output were in bankruptcy. In a "Statement of Facts," issued December 1914, and presented to President Wilson, the operators of Illinois and Indiana set forth the condition of their business:

> The normal state of the coal industry for some years has been such as to endanger the lives of the miners, to waste the coal reserve * * * and deprive these operators of any hope of profit.

Moved by these conditions, the Indiana operators made a formal presentation to the Federal Trade Commission asking for approval of collective action to regulate competition. Existing law gave no authority to approve such action.

The position of the Illinois-Indiana operators at the time was somewhat more difficult than that of other fields, but the broad lines of the picture they presented were essentially true for the industry as a whole in the pre-war years. Soft-coal mining was technically efficient; it had competent managers and able executives. At the same time the industry was heavily overcapacitated, torn by interdistrict rivalries, and characterized by exaggerated and wasteful competition. Dr. Joseph A. Holmes, first Director of the Bureau of Mines, estimated the losses of soft coal in mining at 170,000,000 tons a year.

The World War raised the coal problem in a new form. Congestion of railroad transport created a shortage of fuel at the point of consumption. The inelasticity of demand which had depressed prices to subsistence level in the pre-war days now caused a violent increase. The average spot or open market price jumped from $1.30 f. o. b. mines, in August 1916, to $4.18 in February 1917. Emergency powers of control were granted to the Executive by the Lever Act, and the United States Fuel Administration was created to fix maximum prices, speed up the distribution, and ration the limited supply by priorities in use. Throughout the winter of 1917–18 control of the fuel supply was among the most urgent problems of industrial mobilization.

For 4 years after the war, the coal problem remained in the public mind as one of shortage and high prices. In 1919, and again in 1922, disputes between operators and miners shut down the output of the organized fields. The suspension of 1919 involved 418,000 men, who were idle for 6 weeks. The suspension of 1922 involved 461,000 bituminous miners and also 142,000 anthracite miners, a total of 603,000 men, who were idle on the average for 4½ months. The supply was further curtailed by shortages of railroad cars, aggravated by strikes of the railway switchmen in 1920 and of the shopmen in 1922. Abroad, labor disputes in the British mines in 1920 and 1921 and occupation by the French of the Ruhr coal mines in 1923 created an abnormal demand for the export of American coal. Thus, the condition of shortage and high prices lasted intermittently from 1917 through 1922. During much of this period coal mining was a highly profitable business. In the runaway market of 1920, spot prices at the mines rose during one month to a peak of $9.16 a ton. Average realization on all coal for the year 1920 was $3.75 a ton.

Government control of distribution was revived in 1919–20 under authority of the Lever Act, and in 1922 under the priority powers of the Transportation Act. Special legislation to meet the 1922 crisis was thought necessary, resulting in the Federal Fuel Distributor Act, effective one year from September 22, 1922. Throughout this period of shortage, the country was acutely conscious of its dependence upon bituminous coal. Bills for permanent regulation were introduced and debated, and in 1922 a special commission with statutory powers to investigate and report to the Congress was appointed under the chairmanship of John Hays Hammond.

After 1923 the shortages came to an end, and the conditions of surplus capacity, declining prices, cut-throat competition, and pressure on labor standards which had characterized the pre-war years reappeared in intensified form. The war had led to further expansion in capacity. It had likewise stimulated economies in use. Passage of the Federal Water Power Act in 1920 opened new hydropower sites to development. A combination of factors stimulated the growth of oil and gas. Before the war the demand for bituminous coal had steadily increased, the production reaching a wartime maximum of 579,000,000 tons in 1918. Thereafter, the former increase disappeared, and during the 1920's the output fluctuated now above and now below a stationary plateau, the average for the decade being 510,000,000 tons a year.

The combination of increased capacity and stationary demand forced a drastic liquidation. From 1924 to 1929, when business in general was extraordinarily prosperous, bituminous-coal mining suffered acute depression. In each year of this period, the industry suffered a net loss, as shown by Federal tax returns. In 1928 the loss was $24,500,000; in the boom year 1929, $11,800,000. The average sales realization, f. o. b. mines, declined from $2.68 in 1923 to $1.78 in 1929. More than 200,000,000 tons of mine capacity was forced out of production, and 3,271 mines—commercial, not wagon, mines—were shut down or abandoned. The closing of these mines involved the premature abandonment of several hundred million tons of our finest coals, much of which was left underground under conditions which render its subsequent recovery possible, if at all, only at great increase in cost.

The chief burden of the readjustment rested upon the mine workers. Two hundred thousand men lost their jobs. The machinery of collective bargaining was broken, and the area covered by wage agreements reduced from 70 percent to 20 percent of the industry. Wages declined everywhere, especially in the fields unorganized. The process was accompanied by bitter industrial disputes.

After 1929 the position of the industry grew still worse, intensified by the depression of all business. Wages were further reduced in the South to levels of subsistence. Existence of a special need for relief was early recognized, and in 1931, 2 years before the Federal Government accepted general responsibility for relief, President Hoover requested the American Friends' Service Committee to undertake child feeding in the bituminous coal fields.

The Bituminous Coal Act of 1937 is a crystallization of 25 years of investigation by the Congress and the Executive of the problems of coal mining. Between the congressional investigation of the Colorado strike in 1914 and the passage of the present law, there were no less than 18 hearings, investigations, and special reports on the coal industry. The act of 1937 represents a growing conviction that something had to be done.

In bringing the coal industry under public regulation, the United States was repeating the experience of virtually every other coal-producing country. Our action was not conscious imitation, for it is clearly traceable to local origins. The point is, rather, that as with the problem of unemployment, developments in the New World followed in time sequence those in the Old. Much as we find ourselves embarking on social security and the regulation of wages and hours after they have been accepted as permanent responsibilities by other countries, so now we are embarking upon regulation of the coal industry long after it has become an accepted duty of government both on the Continent and in Great Britain. The fact is significant not only in suggesting that regulation is inevitable but in indicating something of the lines along which it may develop.

The causes underlying this world-wide tendency are partly the pressure of surplus coal-mining capacity. A surplus of capacity had appeared in various countries before the Great War, though less extensive than in the United States. As in America, the war had forced further expansion at the same time that fuel economy and the competition of oil, gas, and hydropower were curtailing the demand for coal. In large part the causes underlying regulation are most fundamental. They include the difficulty of adjusting capacity to demand inherent in coal mining, where shutting down entails heavy maintenance costs or premature abandonment. Equally serious are the difficulties of preserving fair labor standards where wages constitute so large an element of cost and where the offering of a small tonnage in excess of immediate requirements has so depressing an influence on price. All countries have likewise recognized the importance of fuel as the base of modern industry. In the United States a special problem has arisen in the widespread waste of the underground resources which accompanies destructive competition. The Hammond Commission (1923) placed the avoidable loss of coal in mining at 150,000,000 tons a year, equal to the annual bituminous production of postwar Germany.

Under these conditions, some form of public regulation of bituminous coal is clearly necessary. It cannot be undertaken by the States, because of the intensity of interstate competition, and it has, therefore, become a responsibility of the Federal Government.

The particular form of regulation written into the 1937 Coal Act undoubtedly represented majority opinion within the industry as to the best approach to the problem. It provides for a system of fair minimum prices at the mines, and of marketing regulations designed to outlaw unfair competitive practices. Administration is entrusted to a Federal Commission. Representation of the industry is provided through district boards of producers, which have statutory powers and duties but operate under supervision of the Commission. Consumers are represented by the provision of an independent consumers' counsel.

The law builds largely upon the experience of the N. R. A. Bituminous Coal Code, promulgated under the National Industrial Recovery Act. All disinterested students recognize that the N. R. A. Coal Code represented an enormous forward step. It provided, for the first time, a means of common counsel and collective action in an industry previously torn by district rivalries and cutthroat competition and incapable of either formulating or prosecuting any unified policy. Under the code it became possible to establish collective bargaining on an industry-wide basis. Ancient abuses were swept away, hours of labor shortened, and wages notably increased. Aside from its labor standards, the N. R. A. code sought to stabilize the market by setting minimum prices. New leadership developed within the industry, and the problems of determining what constitutes a fair price and of adjusting differentials in price between one district and another were met with a large measure of success. The weakness of the N. R. A. code lay in unwise delegation of power to the code authorities without sufficient standards for their guidance, and in lack of adequate means for enforcement. The 1937 Coal Act seeks to remedy these defects by providing penalties for violation, by laying down detailed standards, and by placing responsibility in a National Bituminous Coal Commission. Producers violating the Code become liable to a 19½-percent tax. Minimum prices are to be fixed so as to reflect relative market values, avoid discrimination, maintain existing competitive relationships, and yield an average income equal to average cost. In the last respect the standards prescribed differ from those commonly laid down for the guidance of railroad and utility commissions. The act does not attempt to insure "a fair return on investment" but merely to provide that average return shall not be less than average cost, carefully defined.

In the event that prices rise unduly above the prescribed minimum, the Commission is instructed to fix maximum prices. The prospect of an increase sufficient to call for the fixing of maxima is, of course, remote, but the power would be indispensable in a national emergency, and it emphasizes the fact that the law is a system of public regulation rather than a delegation of authority to industrial groups.

It is too early to render a final verdict on the operation of the new law.

Since the decisions of the Commission have the force and effect of law, subject to judicial review, they must be reached with the care and orderly procedure appropriate to a regulatory body. The Commission is now proceeding to meet such standards. It is well to bear in mind that while the act is limited to 4 years, the problem with which it deals is not a short-lived emergency. What we are witnessing is probably the beginning of public control, which, in some form or other, will be a permanent national responsibility. It is therefore of the utmost importance that the Commission build firmly so that any subsequent modifications of approach can be intelligently made.

Among the administrative problems raised by the act is the application, in so widely scattered an industry, of the legal requirement that any person interested is entitled to a full and fair hearing. Extension of this principle from the field of public utility regulation, where the regulatory commission deals with a limited number of large corporations, to an industry of many thousand competing units supplying some millions of ultimate consumers raises novel issues in public administration. The problem is to safeguard the rights of the individual businessman, without a degree of delay that would, in effect, deny to Government the exercise of its constitutional powers.

The Commission's procedure under the law is now marked by evident desire to accord all concerned a full opportunity to present their views and by a careful marshalling of the facts. The act prescribes three steps in the establishment of minimum prices, (a) determination of the basic costs, (b) proposal by the district boards of minimum prices, f. o. b. mines, and (c) coordination of the proposed prices in common consuming markets. The first two of these steps have been completed as this report is written, and the third stage is under way.

The possible evolution of American policy toward the coal industry becomes clearer in the light of European experience. Continental and British control of coal mining began, like American, with the regulation of prices. But there has been a clearly defined tendency to supplement price control with cooperative marketing associations, or with the allotment of tonnage quotas. These ideas find expression in the Bituminous Coal Act in section 12, which authorizes the creation of cooperative marketing agencies under the supervision of the Commission. Membership in a marketing agency is open only to producers who accept the act. Approval may not be granted unless the Commission finds that "the agreement under which such agency or agencies propose to function (1) will not unreasonably restrict the supply of coal in interstate commerce, (2) will not prevent the public from receiving coal at fair and reasonable prices, (3) will not operate against the public interest, and (4) that each such agency and its members have agreed to observe the effective marketing regulations and minimum and maximum prices from time to time established by the Commission and otherwise to conduct the business and operations of the agency in conformity with reasonable regulations for the protection of the public interest, to be prescribed by the Commission."

Subject to the approval of the Commission under these standards, "a marketing agency may as to its members, or such marketing agencies may, as between and among themselves, provide for the cooperative marketing of their coal, at prices not below the effective minimum prices, nor above the effective maximum prices prescribed in accordance with section 4."

To date, applications for approval have been made by 9 regional marketing agencies, with membership of 129,000,000 tons annual production. Seven of these have been granted provisional approval, and 2 are pending before the Commission.

If British experience is any guide, this provision for marketing agencies is likely to prove one of the most constructive features of the act. The utility of the marketing agency was recognized by the Supreme Court in its decision approving Appalachian Coals, Inc., the first of such agencies, organized in 1932. Section 12 provides a place for cooperative marketing in the framework of regulation. In the absence of public supervision, the field of marketing agencies was limited. Supervision by the Commission throws adequate safeguards around their operations, and marketing agencies are now in position to support the objectives of the law by the instrumentality of private contract.

Section 14 (a) of the law instructs the Commission to make investigation of the need of control of coal production and the means for such control, including the allotment of quotas, and to report its recommendations to the Congress.

The act, therefore, contains its own provisions for evolution, should experience under the structure of minimum prices, when established, make some modification of the primary system of price control desirable.

Meantime, it is clear that wise administration would seek a careful testing of the operation of minimum prices, and that neither time nor expense should be spared to make the test conclusive. It is crucially important that the understandable desire of the industry for immediate relief from its financial losses, severe though they are, should not be allowed to hurry the Commission into precipitate action, without fair hearing of the persons affected or without sufficient evidence.

The administrative responsibilities raised by the act are undoubtedly among the heaviest laid upon any public body. The task resembles in many ways the regulation of the railroads under the Interstate Commerce Commission. It is clear that this task demands exceptional judgment and ability on the part of the Commission, and an expert staff of the highest professional competence. The act is largely self-financing since the revenue derived from the tax of 1 cent per ton paid by all producers should normally be sufficient to cover the costs of administration.

The Coal Act is a forward step in the evolution of a permanent national policy toward the greatest of our energy resources. Whatever modifications the experience gained under its 4 years of life may suggest, the need for public supervision of the coal industry will remain. A generation of experience before the war and the lessons of the years 1924 to 1933 prove that uncontrolled competition under the peculiar conditions of this industry leads to financial loss, depresses wages, unsettles labor relations, and wastes resources. The rule of enforced competition visualized by the antitrust laws, however salutary for business in general, produces unfortunate results when applied to the exploitation of this widely scattered and exhaustible resource. Some device for unification of policy is needed, and if for no other reason than to protect the consumer, this requires public supervision.

The soundest form of permanent regulation will be that which grows most naturally out of past and present experiences and which develops in largest degree the capacity for leadership and organization from within the industry. The main objectives are clear. The first is to provide means for effectively balancing production against requirements, whether by control of prices, by control of distribution, or by both means. The second objective—less immediate but more fundamental—is to control the opening of new mines and to prevent the expansion of capacity beyond reasonable needs. Safeguards must be provided for the maintenance of labor standards, and the rights of the consumer must be protected by Government supervision of the system of regulation.

Improved economic conditions should permit the industry to take steps to minimize resource waste and encourage the use of State or Federal authority to that end. As long as coal mining operates in surroundings of poverty, no State can well exercise its constitutional powers to outlaw wasteful practices. The first necessary step in reducing the preventable wastes of coal in mining is to place the industry on a stable economic basis.

VIII. Public Policy toward the Oil and Gas Industries [7]

The rise in the use of petroleum and natural gas during the twentieth century has been greater than the growth of the Nation's total energy supply. In 1899 petroleum accounted for 4.5 percent of the country's energy supply and natural gas for 3.2 percent, or a total of 7.7 percent. In 1937, when both petroleum and natural gas reached peaks of relative importance, petroleum accounted for 32.4 percent of the national energy supply and natural gas for 10.4 percent, or 42.8 percent for the combination of these two energy resources. Although some of the growth in the use of these two products represents a shift from coal to oil and gas, most of the gain in oil, especially since 1926, must be attributed to the development of new forms of transportation. During the first 40 years of the oil industry the principal product was kerosene, and the main use of that product was for illumination. About 30 years ago the emphasis on products started to change from kerosene to gasoline, and by 1911 the quantity of gasoline produced exceeded that of kerosene; since then gasoline has completely overshadowed kerosene.

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[7] For supporting evidence and detailed analysis, see the following sections of the accompanying report: Pt. I, sec. II: The Petroleum and Natural Gas Industries; pt. II, sec. I: Fuel Reserves, (2) Petroleum, (3) Natural Gas; pt. III, sec. II: Phases of Technology in the Petroleum Industry; pt. IV, sec. I: The Conservation Movement with Special Reference to the Mineral Fuels; pt. IV, sec. II: The Connally Act: Background.

In terms of products, one might characterize the first 40 years of the oil industry as designed for illumination and the past 30 years as designed for power. The present great economic importance of petroleum results from its use in transportation industries and, primarily, of course, in the operation of motor vehicles—automobiles, buses, trucks, tractors. The importance of oil in the transportation industries stems also from the widespread use of residual fuel oil and Diesel oil by ships and railroad locomotives, and the use of gasoline for airplanes and motorboats. The entire motor transport is dependent on petroleum products, and it has been estimated that for all the methods of transportation approximately 60 percent of the power requirements are supplied by gasoline or by fuel oil. For all practical purposes it may be said that 100 percent of the energy requirement of automobiles and airplanes is derived from gasoline; 93 percent of the total tonnage of ocean-going vessels of the United States merchant marine is moved by oil either in Diesel motors or as fuel under boilers; and practically all vessels of the United States Navy are powered by fuel oil or gasoline. Perhaps no product has produced more economic and social changes than gasoline, as the entire fabric of the transportation system has been changed by the use of automobiles and airplanes. Without gasoline our agricultural industry might revert to horse and mule power, but our urban commerce and manufacturing industries could not maintain their present organization without gasoline.

The growth of the petroleum industry during the past 30 years has been closely coordinated with the growth in automobile registration and use. The rapid expansion in the use of gasoline is roughly indicated by the increase in motor-vehicle registration from 8,000 in 1900, to 468,000 in 1910, to 9,232,000 in 1920, and to 26,445,000 in 1930. The most rapid rate of increase in registration occurred prior to 1920, and during the depression years there was a decline in registration. By the end of 1937, however, registration had increased to 29,655,000. Since 1920, although the rate of increase in automobile registration has been less than that in the period between 1910 and 1920, there has been a pronounced increase in the volume of gasoline consumed per vehicle in use.

The oil industry has kept up with the increase in the demand for gasoline so successfully that the price of gasoline has tended to drop more rapidly than that of other wholesale prices since 1920. Part of this decline in price has been due to technologic improvements in production and refining of oil, but part of it is due also to the pressure of crude oil upon the market consequent to a high activity in the search and drilling for oil without the means of assuring the employment of efficient production methods. The paradox of the petroleum industry is that since at no time is there a proven reserve adequate for any long period, keeping pace with demand requires continuous exploratory effort in order to provide for the future; but the high potential output secured as a result of exploration and drilling exerts an immediate depressing effect upon the industry.

In order to maintain a rising volume of petroleum products many new fields are required. Moreover the magnitude of demand places the emphasis on securing large flush production. Production has grown so much in the past 20 years that at the end of 1937 no one field in the United States had produced in its entire history the equivalent of the 1937 output. Only the great East Texas field, with an accumulated production of 1.13 billion barrels at that time, had approached the 1937 domestic output of 1.28 billion barrels. It should, of course, be remembered that the East Texas field, throughout most of its life, has been under some form of proration.

With the extension of the demand for petroleum, discovery and exploratory efforts have increased. The technology of search has improved, and today oil is being found by methods that were not available a decade or so ago. The extension of the reserve is not entirely from new discoveries but is, in part, the result of the extension of known fields, laterally and vertically. Although much confidence is placed in the possibility of additional discoveries by deep drilling, it must be noted that such extension of the reserve is subject to both technological and financial limits. Deep wells are costly and, unless operated in accordance with the best engineering practices now known, are a serious financial risk, because normally, oil wells permitted to flow without any control dissipate the reservoir energy rapidly and consequently, within 2 or 3 years after discovery, retrograde from flush production to pumpers. In wide open production, a large percentage of the oil that could normally be secured through efficient operations is lost unless comparatively high cost methods of secondary recovery are introduced.

Since it is scarcely possible to predict the demand for petroleum products over a long period of time and since each year brings discoveries of new oil fields, it cannot be said with any certainty when exhaustion will become a problem in the United States. We have produced a large percentage of our reserves, and we are now using our reserves at a faster rate than the rest of the world; and it is entirely probable that we have discovered a larger total percentage of our total possible reserves than any other country.

At the present time we account for approximately 60 percent of the world's consumption, but only 50 percent of the proven reserve. It is likely, then, that the problem of exhaustion will appear in the United States before it does in the balance of the world.

The rank of petroleum as a source of energy, its vital importance in national defense, its vulnerability to destructive forces in exploitation, and its comparatively small reserve in comparison with the high rate of withdrawal place this commodity in a unique position among the natural resources. The welfare of the nation is so dependent upon a continuous and reasonably priced supply of motor fuel, lubricants, and other petroleum products as to demand the consideration of petroleum from the standpoint of national policy. The necessity of close cooperation between the Government and the oil industry was clear during the participation of the United States in the World War, when a petroleum division functioned in the Fuel Administration. Since 1920 oil development on public lands has been conducted with consideration for the general welfare, and since 1924 the Federal Government has in numerous ways indicated that private operation of the petroleum industry should not run contrary to the welfare of the country as a whole. The interest of the Federal Government in petroleum revolves around the central problem of maintaining an adequate supply at a reasonable price just as long as possible.

The major gains in the conservation of petroleum during recent years have been toward the greater recovery of underground reserves and the securing of a larger percentage of valuable production through refining. Although legislation prohibiting the waste of gas as such is found as early as the 1890's, the significance of the energy value of gas in the reservoir was not generally recognized by the petroleum industry until after 1925. By 1930 most of the petroleum engineers had come to recognize that large ultimate recovery was dependent upon holding as much gas as possible in solution with the oil in the ground and that, in instances where oil production was associated with hydrostatic pressure, it was important to maintain a uniform movement of water into the oil sands as the oil was withdrawn. It has been estimated that operating practices until about 1925 led generally to the recovery of only 10 to 20 percent of the original oil from the reservoir sands. By 1934 improved operating methods had been adopted to the point where it is estimated that a recovery of from 20 to 25 percent of the oil was obtained. With the general adoption of efficient methods of recovery it is estimated that varying amounts from 30 to 60 percent of the original oil in the sand could be obtained by primary methods of recovery.

In the refining branch of the industry the development of the cracking process alone has resulted in the conservation of a great volume of petroleum, for this process makes it possible to secure more than twice as much gasoline from a barrel of crude as could be obtained under the earlier form of straight distillation. The industry has expended vast sums of money in perfecting methods and equipment for the production and refining of petroleum, and in this work there has been a considerable degree of cooperation between the industry, the oil-producing States, and various agencies of the Federal Government.

In spite of all that is known concerning production methods, however, there is no way in most States by which those who desire to produce oil without waste can enforce their wishes upon those who prefer to exploit wastefully. Various attempts have been made as between individuals, corporations, the States, and the Federal Government, to secure the necessary degree of cooperation for large ultimate recoveries of petroleum from the underground reservoirs. Among the earliest attempts in this direction was the voluntary unitization of oil pools. In this type of operation even though the methods applied to the single pool might be efficient, the production methods followed by operators in nonunitized pools might destroy the economic benefit of unitization. In one large oil-producing State the restriction of oil production is virtually dependent upon voluntary agreements, and although a very high percentage of the producers agree, those who do not for one reason or another care to go along with the program are in position to do as they please and consequently impair the results of the larger group. In several States the restriction of production in flush pools is directly traceable to keeping down the quantity of oil available to the market demand. Several States have laws that make it possible for their regulatory bodies to apply conservation principles to oil production. A number of oil-producing States have no legislation that could be considered effective either in proration to market demand or in the conservation of reservoir energy.

Although proration to market demand is sometimes referred to as a conservation method, such laws do not necessarily result in the prevention of underground waste. It is, of course, possible that the quantity of oil permitted to be withdrawn from a given oil pool may be the proper quantity with respect to the most efficient operation of the pool, but it does not follow that it has to be. Proration to market demand carries with it primarily the idea of price. Although production procedure is likely to be more economic and more in line with good production practices at $1 a barrel than at $0.20 a barrel, measures designed primarily to support price in and of themselves do not create a situation designed to prevent waste. Depressed gasoline markets at times have resulted in demoralized crude-oil prices, with vitiating effects upon conservation practices. Several proposals have been suggested as to methods which would prevent marketing conditions from having an undesired result upon production, but as there is no obvious solution, this problem merits further consideration.

Present Federal legislation directed specifically toward the furtherance of a continuous supply of petroleum from private or State-held lands consists of the law commonly referred to as the Connally Act, administered by the Secretary of the Interior and the act consenting to the Interstate Oil Compact. The first of these, the Connally law, is designed to help the States enforce their oil laws by preventing the movement in interstate and foreign commerce of oil produced in violation of State laws. The second of these is a treaty approved by Congress between a number of oil-producing States authorizing them to work toward uniform conservation laws. The Interstate Oil Compact has been of value in providing an agency through which State officials might meet in common discussion of their problems, but several of the important oil-producing States are not members of the Compact, and not all the member States have oil conservation laws. The Connally Act has served a useful purpose in helping certain States to enforce their conservation laws by keeping oil produced in violation of these laws out of the stream of interstate and foreign commerce. The enforcement of that law has been notably effective in assisting the State of Texas to control the production of the East Texas oil field. The benefits of the Connally Act, however, are not available to the oil producing States that do not have effective conservation laws, and the act does not prescribe standards for production.

Perhaps the strongest basis for Federal regulation of production and distribution of oil and gas lies in the Federal Government's power to regulate interstate commerce. The commerce clause of the Constitution has been broadly interpreted in the past 2 years. The cases relating to the power of the National Labor Relations Board to regulate industrial relations of companies engaged in interstate commerce indicated in 1937 that the commerce clause applies to industrial concerns which obtain a majority of their raw materials from other States and which sell most of their products to customers in other States. Moreover, the Federal courts have held that although activities may be intrastate in character when separately considered, Congress cannot be denied the power to regulate them if they have such a close relation to interstate commerce that their control is appropriate to protect that commerce from obstruction.

More recently, the power of the Federal Government over interstate commerce has been extended in the case of an electric utility company, where it was held that the Federal Government has jurisdiction over a company whose operations are entirely intrastate in character but which furnishes services essential to the maintenance of interstate commerce. It was pointed out in the opinion that serious interruptions might occur in interstate and foreign commerce if industrial strife stopped the operation of the services of that utility. Moreover, it was held that the exertion of Federal power does not have to await the disruption of that service.

This decision would seem to furnish a basis for Federal regulation of production of oil and gas and of conservation measures looking to the protection of the public against the waste of an irreplaceable resource. The production and transportation of oil and gas make up a stream of interstate commerce so continuous and so widespread and so vital to the country that the legal basis for protection of the Federal interest is scarcely subject to debate. Ineffective conservation of oil and gas resources will hasten the rise in prices which the agencies of commerce and other consumers will have to pay for their fuel. The consequences of waste of oil and gas and the early exhaustion of limited resources would surely result in a far more severe interruption to interstate commerce than would a strike in an electric-power plant in New York City. In addition, the power of the Federal Government to provide for the national defense offers a sound basis for regulations aimed at conserving oil and gas. In time of war this power would undoubtedly become operative, but the adequacy of a future supply imperatively requires peacetime protective measures. Not only are petroleum products essential to the Army and Navy, but it is true also that manufacturing and transportation facilities, vital to the Army and Navy, are dependent for their continued operation upon petroleum. It has been estimated, for example, that during a national emergency the demand for petroleum would increase by one-fourth. At the present rate of consumption this increase would amount to about 800,000 barrels per day. Just as the Supreme Court of the United States has within recent weeks held that the exertion of the Federal power does not have to await the disruption of services essential to the maintenance of interstate commerce, so may it be declared with emphasis that the exercise of the power to provide for the national defense does not have to await the arrival of a national emergency. Petroleum is vital in the national defense, and to defer the application of adequate conservation measures until the declaration of a national emergency is almost as illogical as to defer similarly the construction of battleships.

The problem of conservation has not been solved by the regulation of the petroleum industry now in force in those States that have laws. No State is now in position to protect itself from another State, and consequently no State can in equity to its own industry enforce regulations appreciably more effective than those of other States competing for the same market. Production without any thought of a large ultimate yield, that is, wasteful production, may seem more immediately profitable than production controlled to secure more oil over a larger period. The State looking to the future of its tax returns should recognize that, although under wide open production there may be a large tax fund immediately available, the total is sure to be reduced in the long run by the reduced ultimate production. Furthermore, the economic decadence of communities built on oil fields prematurely exhausted by wasteful methods constitutes a serious social problem.

In order to secure the benefits of a continuous stream of reasonably priced liquid fuel for as long a period as possible for the national defense, for the people as a whole, for all of the States, oil-producing and non-oil-producing, and to protect those States that desire conservation against those considering only the immediate gain, the Federal Government should be in position, in cooperation with the States and the industry, to establish standards for production designed to prevent waste, to encourage conservation, and to protect interstate and foreign commerce from the burden of oil produced in violation of such standards. It may or may not be possible legally to require oil moving solely in intrastate commerce to be produced in accordance with Federal standards, but it must be recognized that, regardless of whether the oil moves outside of the State in which it is produced or is consumed within the State, any oil ultimately affects all other oil.

As more than half of the natural gas produced is incident to the production of oil and as the production of such gas is directly related to oil conservation methods, most of the problems of gas production would be solved by the establishment of standards for oil production.

The change from the present system does not need to be drastic, although more uniformity and better coordination are imperative. To achieve these ends an appropriate Federal agency would be required to administer the Federal interest in oil and gas conservation.

Considerable advance in conservation laws, regulations, and enforcement has been made in several States during recent years, and Federal legislation in the form of the Connally Act has supplemented such State activity. Work already accomplished has the advantage of having been tested legally, and a substantial recognition of the validity of these conservation efforts has been accorded. The gains so far accomplished by some of the States and the Federal Government should not be lost, and future legislation should be built upon this foundation of State and Federal cooperation. The Connally Act has demonstrated the possibilities of such cooperation. The recognition of the mutual interests of the States and the Federal Government—each in its special field of activity—must serve as the basis for the enactment of more comprehensive legislation on oil and gas.

It is recognized that the development of minimum standards for the production and transportation of oil and gas designed to further the national interest in conservation of these resources is a complex problem, and that such standards should be developed in cooperation with the State regulatory agencies and the representatives of the industry. This process will inevitably be time-consuming. In the meantime, the Connally Act expires during the current year. In order, therefore, that the change may be brought about gradually and with the minimum of readjustments, it is recommended that this measure be extended for such time as may be necessary for the framing and enactment of an adequate Federal oil and gas measure. Therefore, it is further recommended that such a Federal measure be enacted defining in general terms minimum standards for the production and transportation of oil and gas; creating an appropriate Federal administrative agency; and providing for the conduct of hearings by that agency in order that the experience of the Federal Government, the State regulatory commissions, and the industry may be pooled in the establishment of detailed standards and regulations designed to protect the national interest in the scientific production and conservation of these irreplaceable resources. It is recommended also that such legislation provide a reasonable period—say, 6 months—between the promulgation of these regulations and their enforcement to give the State regulatory agencies opportunity to bring their own regulations in conformity with the minimum national standards, thereby minimizing the necessity of Federal supervision.

Regulation under Federal auspices should be coordinated with a rational policy concerning exports and imports of petroleum undertaken with the aim of conserving the Nation's resources. The Department of State has in the past been critical of proposals to place restrictions on the importation of raw materials which are produced in insufficient quantities in this country, or the supply of which is exhaustible; and the Department has made it clear that the burden of proof rests with those who propose such restrictions to supply evidence that there is a necessity for such action. In response to requests from congressional committees for comments upon bills dealing with this subject, the Department has taken the position that wise national policy would tend to avoid rather than to seek the imposition of any obstacles to the importation of petroleum, since such action would have the effect of hastening exhaustion of a limited and irreplaceable natural resource. The petroleum products normally imported into this country are, generally speaking, complementary to American petroleum products, yielding a high proportion of heavy fuel oil and asphalt, both of which are in demand in this country and unobtainable, at least in like quantity and quality, except from California fields. It is apparent from reference to the statistics of trade in petroleum that imports of even these relatively noncompetitive products have not been large in comparison with domestic production and have been exceeded, in both volume and value, in every year since 1922 by exports of crude and refined oil. It is recognized by the Department of State and by the other interested Departments that numerous factors deserve careful consideration in determining policy as regards the importation of petroleum and petroleum products, such as the effects, direct and indirect, of such importations upon production, employment, and prices in the domestic oil and coal industries, upon industrial activity and employment generally, and upon the movement of exports and imports.

Although these proposals properly contemplate a broadening Federal interest, much can be accomplished by State efforts. For example, the change from the mischievous law of capture to the rule of ownership in place clearly calls for State legislation. The law of capture was established by Pennsylvania courts which erroneously based their reasoning on the logic in the English rules of percolating waters and wild game, and by other erroneous analogies the courts have established the ruling that oil and gas belong to the owner of the well from which it is produced, regardless of whether or not it had migrated from a neighbor's land. Correlative rights in an underground reservoir are not recognized, and each owner is permitted to drill and withdraw oil exactly as he pleases, with no regard whatever for the most efficient development of the entire pool. If a landowner should produce oil by draining from neighboring land, the only recourse the neighbor has is to drill an offset well. Consequently, when a new pool is discovered, each operator races to drain the field before the oil migrates and is produced through a neighboring well. Competitive production results in a waste of the oil, since no operator can retard his production without losing to a neighbor some of his oil. The law of capture and the small scattered holdings and the leasing system all combine to force operators to produce at as rapid a rate as possible. Accordingly, the reservoir energy in new pools is expended at an excessive rate. In many States the courts have already modified the rule of capture so that a landowner can recover only a certain amount of oil within a given period. The setting of "ratable takings" and of well-spacing provisions has been established as part of the regulatory systems of most oil-producing States and upheld by the State courts. Although the right of capture has been modified somewhat, it needs to be completely displaced by a thorough-going law of ownership in place, which would allot to each producer that proportion of the oil and gas in the common reservoir which underlies the land he owns or controls.

The rule of ownership in place is essential if scientific development and operation of oil fields or reservoirs is to be generally adopted, since scientific operation contemplates the operation of any one pool as a unit. In such a scheme royalties are shared on the basis of acreage, oil in place, or some equitable arrangement regardless of the location of producing wells.

The United States is the owner of lands containing about 15 percent of the oil resources of the country and as trustee for the Indians exercises control of important additional areas. Such lands are developed under lease to citizens, associations of citizens, and corporations, and currently between 7 and 8 percent of the oil produced in the United States is obtained from lands under Federal control. Leases provide that operations shall be conducted with reasonable diligence, skill, and care, without undue waste, in accordance with approved methods and practices, and with due regard to the health and safety of workmen. Provision is also made for sale of production at reasonable prices, for prevention of monopoly, and for safeguarding the public welfare. All leases are made subject to operating regulations that specify many features of approved production practices and are under the supervision of petroleum engineers of the Geological Survey who make periodical inspection and take such action as is necessary to enforce the operating provisions of the leases and regulations. Many oil and gas leases have been made subject to cooperative or unit plans of development and operation of individual fields for the purpose of more properly conserving oil and gas resources through orderly exploration, development, and production by methods designed to increase ultimate production and avoid waste. At the present time approximately one-third of the production of oil and gas from lands owned by the United States is secured under plans of this character.

The major characteristics of unit operation are preliminary exploration in the case of new fields, pooling of operating and lease interests, acceptance of standard development and production methods, and the scientific control of withdrawals. Although unit operation may be established in old pools and even in new pools without preliminary study of reservoir conditions, careful definition of the pool limits and of the nature of the reservoir are desirable preliminaries to unit operation. Major commercial exploitation should be delayed until these ends are achieved, and of course, until a satisfactory agreement has been reached defining each owner's proportionate share of the reservoir content. The economic and conservational advantages of scientific unit management of oil and gas pools are so overwhelming and so generally approved by technicians that some legal device of providing for their adoption and enforcement will surely be forthcoming before the threat of exhaustion becomes imminent. Here, certainly, is a ripe field for State action as well as for Federal action. Moreover, the adoption of minimum Federal standards need not stand in the way of experimentation by the States in their adoption of special State standards. The problem of prolonging the life of their reserves and thus of maintaining as long as possible a healthy petroleum industry should be sufficient to challenge the best efforts of the strongest State regulatory commissions.

IX. Undeveloped Water-Power Resources and Public Policy[8]

Use of water power in the United States is about as old as the industrial history of our country. Prior to the development of electrical transmission, however, power derived from falling water could be used only at the fall. The advent of the steam engine afforded vastly wider latitude for choice of industrial location, for the steam engine could be used wherever fuel and boiler water could be had cheaply. Wood was available almost anywhere in the inhabited sections, and boiler water was available from either streams or wells almost anywhere back of the saline reach of tidewater. As lumbering, clearing for farms, forest fires, and use of wood for fuel caused here and there the beginnings of scarcity of wood, the canals and railroads made more distant wood, and (later) coal, available. Moreover, systems of public water supply made water more easily available. True, the building of roads, canals, and railroads gave easier accessibility to water-power sites; and the introduction of the hydraulic turbine greatly facilitated the appropriation of water power. Meanwhile, goods manufactured at water-power sites could be transported to the markets also drawing from steam plants. But in most of the country the advantage was with steam power.

With the advent of electrical transmission, availability of the energy of falling water became technologically possible anywhere within reach of transmission from the power site; and from purely local availability that reach has spread so much that energy from a waterfall came to be available in the course of time 100, 200, and on toward 300 miles from the fall. The same distances, of course, hold for a steam-electric plant. But, whereas, formerly, the choice was between water power at the fall only and steam power almost anywhere, water power and steam have become alternative possibilities within transmission distance from the fall, i. e., say, somewhat over 250 miles (a tested distance) for a large power site.

Within reach of such radius, a large hydroelectric plant might conceivably supply electricity anywhere within a circular area of 200,000 square miles centered at the fall, i. e., an area twice as large as the combined land area of the States of New York, Pennsylvania, and New Jersey, or considerably more than three times the area of all New England States combined.

As water power was developed, both irregularity of stream flow and the peculiar adaptability of hydro plants to changing load made advisable the use of hydro plants and steam plants in the same systems, where feasible. And during the 1920's, when huge expansion of the electric utility industry took place, hydro capacity and capacity of fuel plants of central electric stations in the United States advanced in about the same proportions.

Thus, within range of transmission from power sites, water power is directly competitive with fuels as a source of energy. Moreover, even though energy from water may not practicably be used at present more than 200 or 250 miles from the power site, industry can gravitate into the orbit of a water-power site. Therefore, indirectly, water power is competitive quite beyond the economic limits of transmission. Thus, water-power policy is part of an energy-resource policy, whether we will or no.

As a source of energy, water power affects and is affected by the available fuels, but differs from them in that it is not reduced by use. Water power is wasted if not used. As a use of water, power affects and is affected by the other functions and controls of water to which a stream may be adapted. Almost any considerable project for the control or use of an important stream will serve—or can serve—more than one useful purpose. There need be no conflict between the several purposes, including power, if the full possibilities of the stream are realized in the public interest. The objective is to develop each of the resources of a major stream in harmony with the others, to the end that the sum of the potential benefits to the public shall be a maximum.

The total potential average output of electric energy derivable from water power in the United States is at its theoretical maximum about 500 billion kilowatt-hours per year, according to a calculation based on estimates prepared by the Geological Survey. This theoretical maximum, is, of course, not attainable, since it would never be possible on many streams to pass all the floodwaters through turbines.

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[8] For supporting evidence and detailed analysis, see the following sections of the accompanying report: Part I, section III; Potential Water Power in the United States; Part II, section II: Water Power Resources, Part IV, section V: Toward a Federal Power Policy.

The total capacity of water wheels installed in water-power plants generating electric energy for public use in the United States on January 1, 1938, was 10,474,344 kilowatts. The output of these plants in 1937 was 43,702,000,000 kilowatt-hours. Water-power sites whose development probably will become economically feasible when a market for their output exists have been listed by the Federal Power Commission and summarized in a published report. According to a recent revision of these data the total average potential output of these sites is estimated at 273 billion kilowatt-hours per year. The total installed capacity would be 52,322,000 kilowatts, according to the engineering studies on which the estimate was based. Total generation of electric energy (in both fuel and hydro plants) for public use in 1937 was 121,050,000,000 kilowatt-hours; and the installed capacity in these plants amounted to 37,032,000 kilowatts.

It is seen that the feasible undeveloped water-power sites of the United States are estimated to be capable of producing six times as much energy as those now developed, but only a little more than twice the electric energy produced in 1937 for public use by fuel and water power combined. It is also noted that only a little more than one-half of the total theoretical undeveloped output has been estimated as probably economically feasible when markets for the potential output exist.

The factors that may make an individual water-power site economically feasible at some future time are not capable of accurate evaluation, even for the relatively near future of, say, 25 years. Specific conclusions as to individual sites may change as better information is obtained with the passage of time. The economic feasibility of a given hydroelectric project has usually been gaged by comparison with the cost of power from an alternative fuel-electric source; but this depends largely on the relation between the cost of money on the one hand and the compensation of labor on the other. Hydroelectric generating costs are governed largely by the rate of interest, while fuel-electric generating costs are governed largely by the compensation of labor necessary to operate the plant and produce the fuel.

Economic feasibility depends on cost and revenue. The construction cost, too often, is practically unknown because the site has not been adequately explored and detailed designs and estimates have not been made. The potential revenue depends on the characteristics of the power output and on the existence of a market for the power—a market whose location, size, and characteristics must be assumed—and on the assumed competitive cost of power delivered to this assumed market from an assumed alternative source, usually a steam-electric plant operating with fuel at an assumed price. In addition, it appears quite possible that power developments would become desirable at water-control projects—such as flood-control and irrigation dams—not included in the sites on which the figures here given were based. Development of power as an incident to other purposes might bring many additional sites into economic feasibility. Any such broad compilation should therefore not be considered precise or final; changes in the interest rate, the cost of labor, the cost of fuel, the location of the power market, or the characteristics of the power load might greatly affect the classification of many known water-power sites.

Technological changes now in prospect that may affect the feasibility of water power include those relating to long-distance transmission of electric energy. Repeatedly, the engineering limit of transmission has been extended. Twenty years ago it was generally felt that the practical engineering limit had probably been reached and that that limit was about 200 miles. Ten years ago a bold designer would have placed the distance at perhaps 300 miles. Today it is known that we can design, build, and operate lines longer than are justified by immediate economic conditions. When power can be transmitted economically several hundred or a thousand miles, important water-power sources will become available that are now too distant from existing markets.

Transmission in the near future of larger amounts of power to much greater distances and at higher voltages than at present is already definitely foreshadowed by the bold engineering advances that made possible the 266-mile heavy-duty line now operating successfully at 287,000 volts between Los Angeles and Boulder Dam. This line was pioneered, designed, built, and is being operated by engineers of the city of Los Angeles with the cooperation of the Bureau of Reclamation. High-tension transmission of direct-current power, now in a late experimental stage, may further lengthen the technical limit of transmission distance and reduce the cost.

There are rich possibilities for the development of water power as a joint purpose, in combination with other useful purposes to which a stream may be adapted or in combination with measures to control the stream for other reasons. It is probable that many of the original studies from which water-power sites were selected failed to give full weight to such possibilities of multiple-purpose development.

Historically it is true that water-power developments have sometimes been permitted that impaired the usefulness of certain streams for other purposes, and certain streams may have been exploited in such manner as to foreclose or reduce their future usefulness for power. More recently it has been discovered that this apparent conflict can largely be resolved on many streams, and especially on great river systems, if these resources are properly utilized and wisely controlled. It is the duty and the task of the designer and of those who guide the application of public policy to develop all of the potential benefits of great river systems in such manner that their sum shall be a maximum. Each should be and can be developed in harmony with the others; each should contribute its share to obtain a total benefit much larger than would be possible by separate exploitation, and this at lower total cost.

Power requirements of the relatively near future will make necessary new supplies of energy exceeding the potential output of all the available and feasible undeveloped water-power sites in most of the highly industrialized regions of the country. A relatively small growth in the power load, surely to be expected under anything like normal conditions, will bring this to pass in a very few years. The conclusion is inescapable that the potential output from any undeveloped water-power site in these regions can be absorbed by the power requirements of the near future, if it can be delivered to the load and sold at competitive prices.

The total amount of potential and feasible undeveloped water power within present economic transmission distance of the larger industrial and urban areas in the eastern half of the country would not, in fact, supply even their present needs for electric energy without the aid of fuel.

In 13 years the increase in power load would require annually an amount of energy larger than the entire average output of all the feasible undeveloped water sites east of the Mountain and Pacific States, if the rate of growth actually experienced in this region from 1921 to 1929 and again from 1932 to 1937 should continue. By including the tremendous resources of the Mountain and Pacific States and the relatively low increments of power growth they have so far experienced, the indicated period is extended to 40 years. In the Middle Atlantic States—New York, New Jersey, and Pennsylvania—less than 9 years of continued increase would be required.

The actual future power needs of the several regions will, of course, be governed by many factors that may or may not follow the same course as in the 18-year period 1920–37 for which the necessary statistics are available. Growth or decline of population, of industry, and of commerce in specific areas; discovery of raw materials or of processes now unknown; progress in the utilization of fuels or in the design of water-power structures and equipment; changes in the prices of fuel or labor, so largely responsible for the cost of fuel-generated power; changes in the price of money, so largely responsible for the cost of hydrogenerated power—these and other factors beyond the range of ordinary human prediction will govern the actual need for eneragy in a given region in a given future year, and also the proportion of this energy that may then be most economically supplied from hydroelectric sources.

An active public policy of multiple-purpose development of water resources is desirable, in view of the pressing character of problems related to flood control, public water supply, stream pollution, irrigation, and navigation, and in view of positive reasons for public development of water power. An active policy of public development of water power is likewise desirable. Both development directly for power purposes, where there is no conflict with more urgent water control, and the best feasible use of head made available by storage for other purposes would contribute toward the attainment of three major national objectives, namely: (*a*) conservation of scarce fuel materials—petroleum, natural gas, and high-grade coals; (*b*) strengthening the national economy, through bringing about cheaper electricity more widely available; (*c*) strengthening the national defense through better assurance of ample electrical energy in time of war.

Multiple-purpose plans for stream development aimed at the several important purposes, including direct or incidental power production, should be designed and executed in terms of drainage basins or major subbasins. Efficacy of controls requires dealing with the main stem of a stream and with all important tributaries. The Federal Government should have primary authority and responsibility for the design and execution of these multiple-purpose drainage basin plans for development and conservation of water resources. Private business firms cannot be expected to undertake the several important nonpower functions which cannot yield salable products. Moreover, private business firms cannot be expected even to bring about the most economic development of water power, because the necessary storage does not seem to be generally justifiable for power alone. State and municipal projects that harmonize with Federal design are quite possible and to be expected; but, because of the interstate character of most of our important streams and the international character of some, State jurisdiction is too limited for the drainage basin plan.

Federal policy should eventually embrace a degree of control over the operations of private water-power plants in the streams covered by any basin plan, sufficient to insure that they will harmonize with those of the general plan. Uncontrolled operation by private interests would interfere seriously both with thoroughgoing design and with the best coordination of water controls. Federal policy on development of water power should embrace the building or the acquirement of steam plants in connection with any hydro development needing steam-driven capacity for the best balance of system capacity. The location of such a plant need not be in the immediate basin area, for the same plant properly placed might serve as the steam supplement of two or more basin hydro systems.

Design of the power system in any of the basin developments should include, in accord with the best technology of power transmission, the best practicable interconnection (a) of the several plants within a basin system, (b) of neighboring basin systems (within the reach of economic transmission), and (c) the steam capacity built or acquired to balance capacity.

X. The National Defense[9]

Although it may be agreed that the development of a strong and healthy national economy constitutes the best preparation for national defense, there are certain special problems affecting the energy resources which require positive action from the standpoint of an adequate national defense. Fortunately, our energy resources are sufficiently abundant to free us now from dependence on foreign sources; but the rapid depletion of our petroleum in natural reservoirs will eventually bring dependence on foreign sources or on the more costly process of producing oil from coal or shale. A conservation program should aim at the postponement of that day as long as possible. The present special problems concern the underground reserves of helium and petroleum, the provision of sufficient electric generating capacity and of facilities for interconnection, and the planning for wartime control of the distribution of fuel.

The export of helium gas, which is noninflammable and therefore vital for military and naval lighter-than-air craft, is now strictly controlled through a system of export licensing, under supervision of the Secretary of the Interior. Exports to foreign powers for military or naval purposes are specifically forbidden. Recent events in a war-disturbed and war-threatened world amply demonstrate the wisdom of that legislation. It is recommended, therefore, that this policy be continued.

The dependence on petroleum and its products of the naval establishment, of the increasingly mechanized army establishment, and of the air forces of the two services is so great that the national defense interest alone is sufficient to justify the Federal policy recommendations concerning conservation of this resource which have been outlined in a preceding section of this summary. It has been pointed out, however, that normal peacetime interests likewise make a compelling demand for a program of conservation. The Navy's interests and the Army's interests reinforce that general demand.

Although the natural reserves of petroleum in the United States are estimated to exceed the proven reserves of any other country, the peacetime industrial demands upon these natural reserves are such that eventually rigid conservation measures will have to be adopted. In a national emergency, the estimated requirements of petroleum products for industry, for the Army, and for the Navy exceed by nearly twenty-five percent the present peacetime production of crude petroleum.

The present special problem is concerned with naval petroleum reserves. Executive Orders dated September 2, 1912, December 13, 1912, and April 30, 1915, set aside for the exclusive use or benefit of the United States Navy three principal petroleum reserves. Naval Petroleum Reserves No. 1 and No. 2, located in Kern County, California, consist both of Government-owned and privately owned land, whereas Reserve No. 3, located in Natrona County, Wyoming, is entirely Government owned.

The safest reservoir for petroleum is the natural reservoir or geological structure in which it occurs. Thus the maintenance of a naval reserve requires that the oil be left in its natural pools. But the existence of multiple ownership requires that the Government engage in offset drilling to secure its share of oil underlying its own lands. It can be seen, then, that private ownership of lands within a naval reserve makes of that reservoir a diminishing reserve and not a fixed reserve. Outright ownership of an entire pool by the Federal Government is the only condition consistent with the aim of maintaining a naval reserve.

The difficulties here outlined are especially acute as regards Naval Reserve No. 1, almost 90 percent of the area of which is Government-owned. These difficulties led to the passage by the Congress and approval by the President of the Act of June 30, 1938, which proposes three ways of correcting or improving the condition obtaining on Naval Reserve No. 1:

(1) To contract with the private owner to permit the conservation in the ground of oil and gas on the Government's lands and eliminate the necessity of leasing or drilling the Government's land to prevent drainage losses as has been done in Reserve No. 2 and along the eastern boundary of Reserve No. 1;

(2) By exchanging Government lands for private lands so as to eliminate the checkerboarded area by consolidating private land and Government lands so that they will comprise adjoining solid blocks owned

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[9] For supporting evidence and detailed analysis, see the following sections of the accompanying report: Pt. I. sec. I—The Coal Industry; pt. I, sec. II—The Petroleum and Natural Gas Industries; pt. I, sec. III—Potential Water Power in the United States.

respectively by the Government and by the private owner; and

(3) For the Government to acquire the private lands by purchase or condemnation.

If the Government is to purchase or exchange lands in order to secure complete ownership of pools, it is obvious that sound policy requires the fullest information on such pools that competent geologists can provide. The only estimate now available was made twelve years ago by the United States Geological Survey. Progress in geological science and in drilling techniques since that time has been so great and the maintenance of an adequate naval reserve is so important to the Nation that a re-survey is called for. Consequently, it is recommended that funds be provided for a thorough survey of this reserve and for such drilling tests as may be necessary.

Another problem affecting petroleum reserves which merits attention here is that of national policy toward ownership of petroleum and natural gas lying beneath the submerged areas off the coast of the United States between low-water mark and the three-mile limit. Unsettled questions of law are involved, but the very existence of doubt offers an opportunity for the bold assertion of the national interest in any petroleum or natural gas reserves that may be found beneath these areas. It is one of the unfortunate errors of our national development that early in our history the public ownership of all subsurface mineral wealth was not declared; such a step would have been so simple at an early stage and would have meant so much in terms of conservation, and it would be so complex and costly at this stage—not to speak of the wastes of irreplaceable resources that have already taken place. But here and now in 1939 we have one last opportunity to take steps which will reserve to the Nation petroleum deposits that may be of considerable extent. In the 3d session of the 75th Congress a Joint Resolution, asserting the Government's rights to these deposits and setting them aside as a naval petroleum reserve, was introduced, passed by the Senate, reported with amendments by the House Committee on the Judiciary, and committed to the Committee of the Whole House. No final action was taken, owing doubtless to the pressure of other matters and to the early adjournment of the Congress. It is recommended that the substance of this resolution again be presented to the Congress. At this stage in our history it is sheer folly to overlook any opportunity for safeguarding the national interest in petroleum reserves.

Another special problem affecting the national defense is that of assuring an adequate supply of electric energy in time of war. During our participation in the World War acute power shortages developed in some centers, and it has been officially stated that had hostilities continued somewhat longer we would have faced an extreme shortage. Peacetime uses of power have grown phenomenally in the intervening two decades, and the nature of warfare has undergone changes which mean multiplied use of power in time of war. The significance to national defense of adequate supplies of electric power will be apparent when it is recalled that our traditional military policy visualizes only a small standing army. Chief dependence is placed upon the mobilization of additional men and of industry after war is declared. Both peacetime and World War experience indicate that, unless industry is prepared beforehand with power and other necessaries immediately available, the mobilization of an effective army in war may be seriously delayed at a period when time is of the utmost importance. This problem was recently given cognizance through the establishment, by Executive Order, of the National Defense Power Committee, interdepartmental in its membership and under the chairmanship of the Assistant Secretary of War. Although the work of that Committee has not yet been completed, public announcements have made it clear that the Committee is concerned (1) with the creation of an adequate reserve of generating capacity in the chief war-material centers and (2) with the construction of a system of interconnections linking power sources and load centers in order to make the country less vulnerable to attack in time of war, less vulnerable to the emergencies of peace, and better prepared for the continuing problems of peacetime development of the country. Transmission of electric power is in many social and economic essentials closely akin to transportation of commodities. Particularly as the economic limits of transmission are extended, the national interest will be served by coordinated systems of interconnections which would make available in wider markets energy derived from the most economical sources, regardless of whether they are large-scale hydro plants or efficient steam plants. Thus it can be seen that this problem is receiving the attention of the Government. It suffices to say here, therefore, that the aim is a laudable one.

The final special problem of energy resources affecting the national defense is to make adequate provision for the control of the distribution of fuel itself in the event of an emergency. During the Great War, control of fuel prices and rationing of the available supplies were found to be necessary by each of the principal belligerent nations. In the United States the increased demand for coal for munitions manufacture combined with other causes to congest the transportation system, clog the eastern terminals and ports, and for a time to delay the movement of supplies and men. In the meantime, operations of the steel industry were at times curtailed by lack of coking coal. The problems of fuel control were ultimately solved by the Fuel Administration with conspicuous success, but at the costs of long confusion and delay.

The task of administering the fuel supply in a future emergency, insofar as coal is concerned, has been facilitated by passage of the 1937 coal act. The act authorizes the fixing of maximum prices and provides through the district boards of producers and a central commission the necessary machinery of administration. Studies should be made of the supplies and requirements of special-purpose coals for the munitions industries and of savings in transport through the control of cross-hauling and plans should be drawn to coordinate the control of fuel with other phases of industrial mobilization. What has been said here of coal applies with even greater force to petroleum; consequently, it is imperative that Federal machinery be set up for efficient mobilization of petroleum resources in the national interest.

A sound national policy in the world in which we live requires a strong national defense, not merely the provision of battleships and tanks and airplanes, but the strengthening of the national economy wherever weaknesses have developed, or can be reasonably anticipated. The energy resources constitute vital parts of the national economy, and it is the part of wisdom to see to it that the supply of energy in all forms is sufficient for the requirements of peace and sufficient for the emergencies of war.

XI. Toward an Energy Resources Policy [10]

It was pointed out earlier in this report that it is now time to take a larger view; to recognize—more fully than has been possible or perhaps needful in the past—that each of our great natural resources of energy affects the others, either directly through competition for markets or indirectly through the profound importance of energy in the whole pattern of our economic and social life. Bituminous coal, petroleum, natural gas, anthracite coal, and water power—in descending order of relative contribution to the Nation's energy supply—these are the energy foundation stones of our industrial civilization. A policy for any one of these resources is bound to affect its relative position with respect to the others. It is difficult in the long run, therefore, to envisage a national coal policy or a national petroleum policy or a national water-power policy without also in time a national policy directed toward all these energy producers—that is, a national energy resources policy. Such a broad and integrated policy toward the problems of coal, petroleum, natural gas, and water power cannot be evolved overnight, for each of those problems is amazingly complex and in combination they represent not a simple sum of problems but a multiplication of problems. Despite the complexity of those problems, in the national interest we shall have to move in the direction of solutions. Those moves must be made in the light of more facts and especially in the light of a more complete understanding of the facts than is now available.

We should not, and indeed in the long run we cannot, interfere with the use of any national resource for those purposes to which it is best fitted. Coal, oil, natural gas, and water power must serve our needs, each in its proper place and each contributing its best share to the total of national welfare. But the free play of undirected competition cannot be relied upon to resolve unaided the maladjustments in these industries that have disturbed our national economy. We should begin to use our heritage of abundance more wisely.

To attain these objectives it is essential to recognize, first, the interlocking relationships between the several kinds of energy resources; next, their individual and combined effect on national and regional development; next, the social as well as the economic factors in their development and utilization; and finally, the constant element of change.

The widening interest and responsibility on the part of the Federal Government for the wise conservation and utilization of the Nation's energy resources raises many perplexing questions of policy determination. This responsibility cannot be assumed lightly. In essence, there must be adequate planning and provision for studies which will reflect the best technical experience available as well as full consideration for both regional and group interests. Such planning in an advisory capacity could be depended on to indicate the results to be expected from the different policies that might be adopted.

Perhaps ideally, a coordinated policy function for the energy resources should be lodged solely in one Federal agency. Practically, this is difficult, for the legal powers to manage and conserve these resources are widely scattered through many Federal and State agencies. There are now no less than 20 separate Federal bureaus and agencies concerned with the problem, and a careful study to delineate their many powers, duties, and responsibilities would constitute an independent task in itself. Further, there are almost 100 interested State agencies whose many powers interlock with—and in some cases overlap or duplicate—the powers of the Federal agencies. From this confusion of divided responsibility and authority must somehow emerge an integrated national policy for the energy resources.

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[10] For supporting evidence and detailed analysis, see the following sections of the accompanying report: Pt. I, sec. I—The Coal Industry; pt. I, sec. II—The Petroleum and Natural Gas Industries; pt. I, sec. III—Potential Water Power in the United States.

At this stage in our national development an advisory planning group for the energy resources is suggested. This group, however, should comprise only one unit of an over-all planning agency specifically established in the Federal Government to serve the President and the Congress in an advisory capacity on planning and policy matters for all of our national resources.

Members of such an energy resources planning group should include representatives of the industries and of the Federal and State agencies concerned. These representatives should be selected on the basis of their technical competence, practical judgment, and experience; and their activities with the coordinating group should reflect their technical experience and their desire to serve best the national interest.

The organization of such a policy advisory group would not mean the abolishing of the planning functions now carried on by existing agencies. To the contrary, planning in "line" agencies would have to be encouraged and strengthened; for without it the over-all planning group would be left without background, experience, and technical assistance. There is, however, the problem of linking together the planning functions of these separate agencies and of fitting them into the broader, national view of the energy resources in combination.

Generally speaking, two types of planning functions are maintained by the existing governmental agencies that are concerned here: first the function arising out of the straightforward job of conservation administration, and second, that which is incidental to the quasi judicial type of regulation of the energy resources industries. There is nothing incompatible in these two types; rather the apparent inconsistency lies in the different over-all forms of administrative organization from which they spring. Yet to the casual observer there appears to be an inherent conflict which renders almost impossible any attempts to bring together these two points of view.

The major difficulty stems from a general misunderstanding of the underlying assumption regarding the role of the regulatory-commission type of agency in the American system of government. The bulk of regulatory commission work involves the application of legislative "standards" of conduct to concrete cases; a function at once discretionary and judicial and demanding, therefore, both responsibility and independence. On the other hand, there is an administrative group within each such agency which usually carries out certain of the administrative powers delegated to that agency by the legislative body and which, in addition, serves the judicial group of the agency by collecting evidence, presenting cases, and carrying out the details of enforcement.

Obviously, serious difficulties are encountered when such agencies provide for a planning function or cooperate with other agencies in a coordinated planning effort. When representatives of the regulatory agencies cooperate with other agencies in an advisory planning capacity, they are placed in the unwelcome position of proposing a policy which, by implication, carries the official endorsement of the quasi-judicial body which they represent. Such a position, it is often feared, will embarrass their agencies in their subsequent cases, for it is interpreted as a "judicial bent." But this is not an unsurmountable obstacle to the formation of an advisory planning group for the energy resources. The solution is for the agencies themselves to make a formal recognition of the division of labor between their judicial and administrative sections or groups. If, then, the planning function is made clearly a responsibility of the administrative section of the regulatory agency, the way is opened for coordinated planning work of an advisory nature.

In theory, planning by the Federal Government for the energy resources could proceed without assistance or advice from these agencies, but in practice it should not. The interests and groups which they represent and the experience which they have accumulated are too vital and have too great a bearing on national policy to be ignored. Accordingly, the proposed advisory planning group should and must include representatives of the regulatory agencies.

It cannot be expected that such a group can be organized quickly or operate from the beginning without incidental conflicts and confusion. Undoubtedly, there will be difficulties, but these should not preclude the attempt. It should be borne in mind in organizing and carrying forward the work of the planning group that, fundamentally, the responsibility of the Federal Government in planning for the energy resources rests upon the basic assumption that the wise management and use of these resources is necessary in the national interest. Power lies at the foundations of our industrial civilization, and the American economy stands in a favored position by virtue of the bounties of nature. Our problem, fortunately, is not one of stretching a niggardly supply but rather that of wise use of a relatively favorable supply of presently available and potential energy resources. Despite this favorable position, however, the problems of these industries are acute ones—problems concerned with physical resource conservation, with restoration and preservation of economic health in the energy resources industries, and with the well-being of the populations dependent on these industries. Both the diversity of these problems and their interlocking relationships require the weighing of conflicting interests and points of view; and the fact of distribution of regulatory and research functions among many Federal and State agencies suggests the formation of an advisory group representative of these various agencies.

Accordingly, it is recommended that the National Resources Committee, in cooperation with the interested agencies of the Federal Government and with representation for interested State agencies and for the energy resources industries, establish an Energy Resources Committee to function as an advisory planning agency in the formulation of a coordinated national policy toward the energy resources industries.

XII. Summary of Conclusions[11]

The energy resources—coal, petroleum, natural gas, and water power—lie at the foundation of our industrial civilization. Except for water power, they are exhaustible resources, and water power at best could supply only a fraction of our energy requirements. Of the mineral fuels, we have an abundance, in comparison with the rest of the world. Nevertheless, our resources of the higher grade fuels—petroleum, natural gas, and the superior coals—are distinctly limited. From the evidence reviewed in this study it appears beyond argument that the Nation's patrimony in the energy resources should be safeguarded, that a sound national policy must be concerned with the conservation and prudent utilization of these basic resources.

Briefly, our reserves may be stated as follows:

(*a*) Coal of all ranks, 3,000 billion tons or the equivalent of 2,500 billion tons of bituminous coal, in comparison with 1937 production of about one-half billion tons and accumulated production through that year of 23 billion tons.

(*b*) Petroleum in proven natural reservoirs, 15 billion barrels, in comparison with 1937 consumption of 1¼ billion barrels. These proven reserves are equal to about 4 billion net tons of equivalent bituminous coal;

(*c*) Proven natural gas reserves, from 60 to 100 trillion cubic feet, in comparison with 1937 consumption of about 2⅓ trillion cubic feet. The reserve is equivalent to 3 or 4 billion net tons of bituminous coal.

(*d*) Recoverable oil from oil shale has been estimated at 92 billion barrels, or the equivalent of 21 billion net tons of bituminous coal. This oil, be it noted, is recoverable only at a cost far above the present cost of natural reservoir oil. In fact, it is probable from present techniques that coal will provide liquid fuels at lower cost than shales;

(*e*) Feasible undeveloped water-power sites of the United States, when a market for their output exists, are estimated to be capable of producing six times as much energy as those now developed, but only a little more than twice the electric energy produced in 1937 for public use by fuel and water-power plants combined (64 percent by fuel plants and 36 percent by hydro plants). All our water power, including both that already developed and that feasible of development, could produce energy annually equivalent to only about one-fourth of the energy contained in all mineral fuels consumed in the country in 1937 for all purposes. Thus it can be seen that water power can supply only a fraction of our energy requirements. The mineral fuels must bear the main burden.

The fields of remedy in a conservation program seem to lie (1) in promoting greater efficiency in the production of mineral fuels from the standpoint of recovery; (2) in promoting greater economy in the use of fuels; and (3) in placing a larger share of the energy burden on lower-grade fuels and water power. These responsibilities must rest primarily upon the Federal Government, for the Federal Government is the only agency which represents all national interests and the only agency which can effectively cope with interstate problems. The energy-resources industries are thoroughly interstate, in production as well as in the use of their products. Thus the chief recommendations of this study contemplate a continuing or a broadening of the Federal interest. These recommendations may be summarized as follows:

1. *The research function.*—Both fundamental and applied research should be stimulated and supported by the Federal Government in the agencies concerned with the energy resources, and this research work should be vigorously pointed in the direction of conservation of these resources, i. e., toward the efficient use of our energy resources in the interest of the national welfare, the avoidance of unnecessary waste in their production and utilization, and the safeguarding in economic health of the industries and populations on which we rely for the development of these vital resources. Much of this research function can be discharged only by the Federal Government, although important parts of it have been and should be discharged by the State governments, by educational and other quasi-public agencies, and by the affected industries. Wherever conducted, however, this basic function of extending the frontiers of knowledge and application in this field requires and merits continuing and vigorous stimulation by the Federal Government.

2. *Public policy toward the coal industry.*—It has been abundantly demonstrated that unfettered competition in the bituminous coal industry produces results that are destructive of sound national values—destructive of the interests of operators, miners, and the public alike. In the absence of controls, the pressure of surplus capacity in this industry can be relied

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[11] Except for the concluding paragraphs, under the heading "The General Welfare", this section merely repeats in briefer compass the findings and recommendations presented in the earlier sections.

on to bring waste of irreplaceable resources, chronic depression and lowering of economic and social standards in the mining regions, losses to operators, and impairment of earnings and labor standards for the miners. These problems are national problems, and only the Federal Government has powers commensurate with their scope. The distribution of the industry over many States and the widespread interstate distribution and use of its product render State action futile. Thus, it has come to be more or less universally recognized that regulation is required and that Federal regulation is the only effective regulation. The Bituminous Coal Act of 1937, representing this growing conviction that something had to be done, provides for a system of fair minimum prices and of marketing regulations designed to outlaw unfair marketing practices. Although it is too early to render a verdict, it is clear that wise administration must seek a careful and conclusive testing of the operation of minimum prices. Through the provisions with respect to marketing agencies and investigations of the need of production control, the Act offers means of evolution should experience indicate the desirability of modification of the primary system of price control. This Act is a step in the evolution of a permanent national policy toward the greatest of our energy resources, and no effort should be spared to make the test conclusive. The grave administrative responsibilities resting upon the National Bituminous Coal Commission demand exceptional judgment and ability and an expert staff of the highest professional competence.

Whatever modifications the experience gained under the four years of life of the present coal act may suggest, the need for public supervision of the coal industry will remain permanently. Some means are required for effectively balancing production against requirements, whether by control of prices, by control of distribution, or by both. A less immediate but more fundamental need is to control the opening of new mines and retard expansion of capacity beyond reasonable requirements. Adequate safeguards must be provided for maintaining labor standards and protecting the rights of consumers by Government supervision of the system of regulation.

With respect to the anthracite industry, it is to be noted that measures designed to deal with the economic and human distress in that industry in Pennsylvania have recently been proposed by a special State investigating commission. Without in any way passing judgment on those proposals, we make no recommendations here concerning anthracite in the belief that the Commonwealth of Pennsylvania should first exhaust its own remedies. If it finally becomes evident that the Commonwealth cannot cope with the anthracite problem, then it may become necessary to extend the jurisdiction of an appropriate Federal agency to that industry.

3. *Public policy toward the oil and gas industries.*—The rank of petroleum as a source of energy, its vital importance in national defense, its vulnerability to destructive forces in exploitation, and its comparatively small reserve in comparison with the high rate of withdrawal place this commodity in a unique position among the energy resources. The welfare of the Nation is so dependent upon a continuous and reasonably priced supply of motor fuel, lubricants, and other petroleum products as to demand the consideration of petroleum from the standpoint of national policy. Present Federal legislation consists of the act consenting to the Interstate Oil Compact and the law commonly referred to as the Connally Act. The Compact has been of value in providing an agency through which State officials might meet in common discussion of their problems, but several of the important oil-producing States are not members of the Compact and not all the member States have oil conservation laws. The Connally Act has served a useful purpose in helping certain States enforce their conservation laws by keeping oil produced in violation of those laws out of the stream of interstate and foreign commerce. The Act, however, does not make it necessary for oil-producing States to enact conservation laws, and it does not prescribe minimum standards of production. In short, the problem of conservation has not been solved by what is, in effect, delegation to the States of certain powers over interstate commerce in oil. No State is now in position to protect itself from another State, and consequently no State can, in equity to its own industry, enforce regulations appreciably more effective than those of other States competing for the same markets. In order to assure the benefits of a continuous stream of reasonably priced liquid fuel for as long as possible for the national defense; for the people as a whole; for all the States, oil producing and non-oil producing; and to protect those States that desire conservation against those considering only the immediate gain, the Federal Government should be in position, in cooperation with the States and the industry, to establish standards for production designed to prevent waste, to encourage conservation, and to protect interstate and foreign commerce from the burden of oil produced in violation of such standards. The production and transportation of oil and gas make up a stream of interstate commerce so continuous, so widespread, and so essential that the legal basis for protection of the Federal interest is scarcely subject to debate. In addition, the power of the Federal Government to provide for the national defense offers a sound basis for regulations aimed at conserving oil and gas. In time of war this power would undoubtedly become

operative, but the adequacy of a future supply imperatively requires peace-time protective measures. Not only are petroleum products essential to the Army and Navy but it is true also that manufacturing and transportation facilities, vital to the Army and Navy, are dependent for their continued operation upon petroleum. It has been estimated, for example, that during a national emergency the demand for petroleum would increase by one-fourth. At the present rate of consumption this increase would amount to about 800,000 barrels per day. Just as the Supreme Court of the United States has within recent weeks held that the exertion of the Federal power does not have to await the disruption of services essential to the maintenance of interstate commerce, so may it be declared with emphasis that the exercise of the power to provide for the national defense does not have to await the arrival of a national emergency. Petroleum is vital in the national defense, and to defer the application of adequate conservation measures until the declaration of a national emergency is almost as illogical as to defer similarly the construction of battleships.

An appropriate Federal agency would be required to administer the Federal interest in the oil and gas industry and to make necessary rules and regulations concerning the production of and commerce in oil and gas. Such regulation under Federal auspices should be coordinated with a rational policy concerning exports and imports of petroleum undertaken with the aim of conserving the Nation's reserves.

It is recognized that the development of minimum standards for the production and transportation of oil and gas designed to further the national interest in conservation of these resources is a complex problem and that such standards should be developed in cooperation with the State regulatory agencies and the representatives of the industry. This process will inevitably be time-consuming. In the meantime, the Connally Act expires June 30, 1939. In order, therefore, that the change may be brought about gradually and with the minimum of readjustments, it is recommended that this measure be extended for such time as may be necessary for the framing and enactment of an adequate Federal oil and gas measure. Therefore, it is further recommended that such a Federal measure be enacted defining in general terms minimum standards for the production and transportation of oil and gas; creating an appropriate Federal administrative agency; and providing for the conduct of hearings by that agency in order that the experience of the Federal Government, the State regulatory commissions, and the industry may be pooled in the establishment of detailed standards and regulations designed to protect the national interest in the scientific production and conservation of these irreplaceable resources. It is recommended, also, that such legislation provide a reasonable period—say, 6 months—between the promulgation of these regulations and their enforcement to give the State regulatory agencies opportunity to bring their own regulations in conformity with the minimum national standards, thereby minimizing the necessity of Federal supervision.

Although these proposals properly contemplate a broadening Federal interest, much can be accomplished by State efforts. Adoption of minimum Federal standards need not stand in the way of experimentation by the States in their adoption of special State standards. The problem of prolonging the life of their reserves and thus of maintaining as long as possible a healthy petroleum industry should be sufficient to challenge the best efforts of the strongest State regulatory commissions.

4. *Undeveloped water power resources and public policy.*—As a source of energy water power affects and is affected by the available fuels, but differs from them in that it is not reduced by use. Water power is wasted if not used. As a use of water, power affects and is affected by the other functions and controls of water to which a stream may be adapted. Almost any considerable project for the control or use of an important stream will serve—or can serve—more than one useful purpose. There need be no conflict between the several purposes, including power, if the full possibilities of the stream are realized in the public interest. The objective is to develop each of the resources of a major stream in harmony with the others, to the end that the sum of the potential benefits to the public shall be a maximum.

Feasible undeveloped water-power sites of the United States are estimated to be capable of producing six times as much energy as those now developed, but only a little more than twice the energy produced in 1937 for public use by fuel and water power combined.

Technological changes now in prospect that may affect the feasibility of water power include those relating to long-distance transmission of electric energy. Repeatedly, the engineering limit of transmission has been extended. Twenty years ago it was generally felt that the practical engineering limit had probably been reached and that that limit was about 200 miles. Ten years ago a bold designer would have placed the distance at perhaps 300 miles. Today it is known that we can design, build, and operate lines longer than are justified by immediate economic conditions. When power can be transmitted economically several hundred or a thousand miles, important water-power sources will become available that are now too distant from existing markets.

An active public policy of multiple-purpose development of water resources is desirable, in view of the pressing character of problems related to flood control, public water supply, stream pollution, irrigation, and navigation, and in view of positive reasons for public development of water power. An active policy of public development of water power is likewise desirable. Both development directly for power purposes, where there is no conflict with more urgent water control, and the best feasible use of head made available by storage for other purposes would contribute toward the attainment of three major national objectives, namely:

(*a*) Conservation of scarce fuel materials—petroleum, natural gas, and high-grade coals.

(*b*) Strengthening the national economy, through bringing about cheaper electricity more widely available.

(*c*) Strengthening the national defense, through better assurance of ample electric energy in time of war.

Multiple-purpose plans for stream development aimed at the several important purposes, including direct or incidental power of production, should be designed and executed in terms of drainage basins or major subbasins. Efficacy of controls requires dealing with the main stem of a stream and with all important tributaries. The Federal Government should have primary authority and responsibility for the design and execution of these multiple-purpose drainage basin plans for development and conservation of water resources. Private business firms cannot be expected to undertake the several important nonpower functions which cannot yield salable products. Moreover, private business firms cannot be expected even to bring about the most economic development of water power, because the necessary storage does not seem to be generally justifiable for power alone. State and municipal projects that harmonize with Federal design are quite possible and to be expected; but, because of the interstate character of most of our important streams and the international character of some, State jurisdiction is too limited for the drainage basin plan.

Federal policy should eventually embrace a degree of control over the operations of private water-power plants in the streams covered by any basin plan sufficient to insure that they will harmonize with those of the general plan. Uncontrolled operation by private interests would interfere seriously both with thoroughgoing design and with the best coordination of water controls. Federal policy on development of water power should embrace the building or the acquirement of steam plants in connection with any hydro development needing steam-driven capacity for the best balance of system capacity. The location of such a plant need not be in the immediate basin area, for the same plant properly placed might serve as the steam supplement of two or more basin hydro systems.

Design of the power system in any of the basin developments should include, in accord with the best technology of power transmission, the best practicable interconnection (a) of the several plants within a basin system, (b) of neighboring basin systems (within the reach of economic transmission), and (c) the steam capacity built or acquired to balance capacity.

Transmission of electric energy is in many social and economic essentials closely akin to transportation of commodities. Particularly as the economic limits of transmission are extended, we believe that the national interest will be served best by coordinated systems of interconnections which will make available in wider markets energy derived from the most economical sources, regardless of whether they are large-scale hydro plants or efficient steam plants. Such coordinated systems would make the Nation less vulnerable to attack in time of war and less vulnerable to the emergencies of peace as well as better prepared for the continuing problems of peace time development.

5. *Toward an energy resources policy.*—It was pointed out earlier in this report that it is now time to take a larger view; to recognize—more fully than has been possible or perhaps needful in the past—that each of our great natural resources of energy affects the others. A policy for any one of these resources is bound to affect its relative position with respect to the others. It is difficult in the long run, therefore, to envisage a national coal policy or a national petroleum policy or a national water-power policy without also in time a national policy directed toward all these energy producers—that is, a national energy resources policy. Such a broader and integrated policy toward the problems of coal, petroleum, natural gas, and water power cannot be evolved overnight, for each of these problems is amazingly complex. Despite the complexity of those problems, in the national interest we shall have to move in the direction of solutions.

The widening interest and responsibility on the part of the Federal Government for the wise conservation and utilization of the Nation's energy resources raises many perplexing questions of policy determination. In essence, there must be adequate planning and provision for studies which will reflect the best technical experience available as well as full consideration for both regional and group interests.

At this stage in our national development an advisory planning group for the energy resources is suggested. This group, however, should comprise only one unit of an over-all planning agency specifically established in the Federal Government to serve the President and the Congress in an advisory capacity on planning and policy matters for all of our national resources.

Members of such an energy resources planning group should include representatives of the industries and of the Federal and State agencies concerned. These representatives should be selected on the basis of their technical competence, practical judgment, and experience; and their activities with the co-ordinating group should reflect their technical experience and their desire to serve best the national interest.

It should be borne in mind in organizing and carrying forward the work of the planning group that fundamentally the responsibility of the Federal Government in planning for the energy resources rests upon the basic assumption that the wise management and use of these resources is necessary in the national interest. Power lies at the foundations of our industrial civilization, and the American economy stands in a favored position by virtue of the bounties of nature. Our problem, fortunately, is not one of stretching a niggardly supply but rather that of wise use of a relatively favorable supply of presently available and potential energy resources. Despite this favorable position, however, the problems of these industries are acute ones—problems concerned with physical resource conservation, with restoration and preservation of economic health in the energy resources industries, and with the well-being of the populations dependent on these industries. Both the diversity of these problems and their interlocking relationships require the weighing of conflicting interests and points of view.

Accordingly, it is recommended that the National Resources Committee, in cooperation with the interested agencies of the Federal Government and with representation for interested State agencies and for the energy resources industries, establish an Energy Resources Committee to function as an advisory planning agency in the formulation of a coordinated national policy toward the energy resources industries.

6. *The general welfare.*—It is well to remember that the present and proposed regulatory measures discussed in this summary are designed to promote the development of the energy resources industries along lines that will be consistent with the broad national interest. The problems of conservation which dictate these measures are not the result of passing emergencies. Rather, they are continuing problems, and if they cannot be solved by the regulatory approach then we may anticipate with some confidence that there will emerge an insistent and eventually irresistible demand for public ownership and control.

The paramount responsibility of Government is to protect the general welfare. That way lies safely and a progressive evolution of our economy and of our political institutions. The lessons of European developments in the post-war period are clear on this point: to fail to recognize emerging economic and social problems, to fail to foresee the threatening forms they will assume, and to fail to work out logical plans for solving these problems is to neglect the general welfare and to pave the way for extremists. No amount of confusing legalistic discussion of limitation of powers can obscure the reality of the choices before us. We must evolve ways of protecting the general welfare or face the consequences in mass discontent. To protect the general welfare in our time—in an industrialized and urban economy—means above all else to build and maintain in good order a sound economic structure. In an industrial civilization the energy resources constitute the foundation stones in that structure.

The broadening of the Federal interest with respect to these energy resources has been justified primarily on the basis of the need for their conservation, broadly defined to mean their wise use; that is, the efficient use of our energy resources in the interest of the national welfare, the avoidance of unnecessary waste in their production and utilization, and the safeguarding in economic health of the industries and populations on which we rely for the development of these vital energy resources. But it must be observed that the need for conservation is but a special case. The general case is that Government intervenes with control measures when the economic organization of a segment of the economy is such as not to yield socially desirable results. If the economic organization is one of monopoly, "natural" or contrived, Government intervenes to restrain the exercise of the privileges of monopoly; e. g., rate regulation or yardstick regulation of electric utilities. If the economic organization is such that competitive conditions and practices produce chronic depression in the industry and demoralizing distress among those dependent on the industry, then Government intervenes to seek correction of those conditions and practices; e. g., regulation of the bituminous coal industry. If the economic organization is such as to result in grave waste of irreplaceable and distinctly limited resources, then Government may and should intervene to protect the public interest in conserving the supplies of those resources; e. g., the case for the determination and enforcement of minimum Federal standards in the production and transportation of petroleum and natural gas.

It is not likely that backward steps will be taken; it is not likely that we shall retreat from the social and economic advances made in the domain of the energy resources. Rather, it is likely that we shall press on toward the objective of the general welfare.

STAFF STUDIES

ENERGY RESOURCES AND NATIONAL POLICY

NOTE

The publication of these staff reports does not imply that the National Resources Committee or the Energy Resources Committee concurs in the recommendations contained herein. The views and opinions expressed are those of each of the authors responsible for preparing the individual reports.

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INTRODUCTION TO STAFF STUDIES

In accordance with the President's instructions, in his letter of March 15, 1938, to the Chairman of the National Resources Committee, this study of the Nation's energy resources has been focussed on problems of national policy with respect to the prudent utilization and conservation of these resources. The President's letter made clear not only the objectives of the study but also the manner in which the inquiry was to be conducted. First, the time schedule was such as not to permit of further extended research. Second, the nature of the objectives called for a cooperative undertaking by the National Resources Committee and all the other interested agencies of the Federal Government. Thus, the task was one of assembling the existing materials, enlisting the help of the various Federal agencies, and bringing these forces to bear on a major problem of national policy.

The study was launched at an interdepartmental conference held June 29, 1938, and attended by representatives of 8 Federal agencies. In response to suggestions made at that meeting, the list of cooperating agencies was expanded to include 20 agencies, as follows:

- Department of State.
- Department of War.
- Department of the Navy.
- Department of the Interior:
  - Petroleum Conservation Division.
  - Geological Survey.
  - Bureau of Reclamation.
  - Bureau of Mines.
  - Bonneville Project.
  - National Bituminous Coal Commission
  - Consumers Counsel, National Bituminous Coal Commission.
- Department of Agriculture:
  - Forest Service.
- Department of Commerce:
  - Bureau of Foreign and Domestic Commerce.
  - National Bureau of Standards.
- Independent Agencies:
  - Interstate Commerce Commission.
  - Federal Power Commission.
  - Tennessee Valley Authority.
  - Rural Electrification Administration.
  - Securities and Exchange Commission.
  - National Power Policy Committee.
  - U. S. Tariff Commission.

ACKNOWLEDGMENTS

This report could not have been prepared without the effective cooperation of all the Federal agencies concerned with the energy resources. In behalf of the National Resources Committee and personally, I wish to express great indebtedness and profound appreciation to all those agencies listed above. With respect to the authors of sections and chapters, their contributions to this Volume stand as evidence of our heavy indebtedness to them.

For help and advice throughout the course of the study, I must express grateful appreciation especially to A. C. Fieldner, of the Bureau of Mines; to F. G. Tryon and W. H. Young, of the National Bituminous Coal Commission; to W. C. Mendenhall, H. D. Miser, and A. H. Horton, of the United States Geological Survey; to Roger B. McWhorter, Thomas R. Tate, and S. H. Thompson, of the Federal Power Commission; and to John W. Frey, of the Petroleum Conservation Division of the Department of the Interior. Through the courtesy of J. W. Finch, Director, U. S. Bureau of Mines, and David Weintraub, Director of the W. P. A. National Research Project, O. E. Kiessling, of the Bureau of Mines, and D. C. Ashmead, of the Works Progress Administration, very kindly made available unpublished manuscripts, charts, and tables from studies being prepared for the National Research Project. Roger N. Quirk of London generously permitted the use of valuable factual material from his manuscript on regulation of the American coal industry, prepared while he was on leave from the British Mines Department as a Commonwealth Fund Fellow. In the preparation of material for certain maps on water power, B. E. Jones and E. C. Nordeen, of the Geological Survey, and A. K. Mann, of the Federal Power Commission, made valuable contributions. Leo N. Plein, of the National Bituminous Coal Commission and A. G. White, of the Bureau of Mines, prepared detailed estimates of the thermal efficiency of fuels, necessary in the preparation of certain maps. Charles Faunce, of the National Resources Committee, supervised the preparation of all the charts and maps.

Special acknowledgments are due also the American Gas Association, the American Petroleum Institute, and the National Coal Association for helpful material and special compilations of data. Reviews of the experience of the State regulatory agencies under petroleum production-control and conservation measures were made available through the cooperation of the State planning agencies in Arkansas, California, Kansas, Louisiana, Oklahoma, and Texas. The Washington State Planning Council prepared a special study of the energy resources in that State as a demonstration of the possibilities of State-wide studies of this type.

It goes without saying that none of those whose help is acknowledged here bears any responsibility for opinions expressed or conclusions drawn in this study, save as that responsibility is indicated through authorship of a specific part of the report.

As Director of this study, I must express my greatest indebtedness to my associates, J. P. Watson, Glenn E. McLaughlin, and Wilbert G. Fritz, of the staff of the Bureau of Business Research, University of Pittsburgh, who had the task of integrating and synthesizing the material on, respectively, water power, petroleum and natural gas, and coal. Their work was done largely at the University of Pittsburgh, on part-time leave from their regular duties; they were assisted by Florence Hiller, Henry H. Kirtland, Harriet T. Lewis, and Gladys R. Walker. Special acknowledgments are due also Gladys M. Gardner, Secretary of the Bureau of Business Research, who supervised the secretarial work of the Pittsburgh office, and to Edna Birkel, who handled the work of the Director's office in Washington. Robert W. Hartley served ably and untiringly as secretary of the Energy Resources Committee.

RALPH J. WATKINS,
Director, Energy Resources Study.

NOTE

Attention is directed to the fact that since this report was completed, the National Bituminous Coal Commission has been abolished under the President's Reorganization Plan No. 2 and its powers, duties, and functions transferred to the Secretary of the Interior. Also, the Connally Act regulating interstate and foreign commerce in petroleum, which would have expired on June 30, 1939, has been extended for an indefinite period by the Congress.

PART ONE—SECTION I
THE COAL INDUSTRY

By Wilbert G. Fritz[*]

CHAPTER 1.—THE SIGNIFICANCE OF COAL

High productivity in the United States is made possible by widespread use of energy derived from natural resources. The United States consumes more power per capita than any other nation in the world. Heavy consumption of minerals has enabled the Nation to accomplish what human energy supplemented only by work animals, wood, and direct application of wind and falling water could never do. One is led to inquire whether this extensive use of energy can continue or whether limitation of resources will compel an early decline.

Historical Background of Energy Utilization

Throughout history, the pace of industrial progress has been attuned almost directly to the proportions of energy that human beings have been able to apply to productive ends. The multiplication of human effort by the application of resource energy has gained momentum with the passage of time. Domestication of animals, and especially their use for work, was a boon to early civilizations. Leading cultures in all ages owed their existence in large part to concentrated application of energy in one form or another. James Fairgrieve, in contrasting energy use in Great Britain with that in ancient Greece, points out that the great power of Greece was based largely on work done by a servile class.[1] On the average, each Greek freeman had five helots who supplied most of his energy needs.

For many centuries, wind power constituted the chief basis for commercial development. The sailboats of the Phoenicians during the period 1500 B. C. to 400 B. C. enabled that country to gain a position commercially far ahead of its contemporaries, even though the country occupied an area not much larger than the state of Delaware.

Columbus' discovery of America represented an attainment made possible by the application of wind power to the sail. The famous American Clipper Ship era marked the climax of that application. Colonial America depended heavily on water power as a source of energy, and industrialization in New England up to about 100 years ago was based predominantly on the use of water wheels. The Clipper Ship era and the water-power era gave way to the "coal age," which came with the introduction of the steam railroad and the steamship.

Rapid though the development of resource energy was when coal first became the dominant source of energy, the rate of use in recent decades far outstrips that of the earlier period. F. G. Tryon says that during the quarter century ended with 1935 the United States consumed more fuel and more power than in all the previous history of the country back to the days of earliest colonization.[2] Although coal consumption did not grow as rapidly as oil and gas consumption during this 25-year period, it has shown a large net growth; and it supplies at present more than one-half of the total energy derived from coal, oil, natural gas, and water power.

It is generally recognized that the United States uses more power per capita than any other country. This Nation consumes normally 1.6 times as much power per capita as Great Britain, 2.5 times as much as Germany (before the acquisition of territory under the Third Reich), 11 times as much as Japan, and 150 times as much as China.[3] A comparison of human with other forms of energy is of interest in this connection, although no one should assume the possibility of a high degree of accuracy for such a comparison. Professor T. T. Read estimates that human energy in the United States constitutes less than 3 percent of total energy and thus, that more than 97 percent is derived from other sources.[4] According to Professor Read's study, about 35 units of mechanical energy are used for each unit of human energy.[5] Every person in the United

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[1] Fairgrieve, *Geography and World Power* (London, University of London Press, Ltd., 1924), p. 316.

[*] Bureau of Business Research, University of Pittsburgh.

[2] Testimony in the *Carter Coal* case, Supreme Court of the United States, October Term, 1935, No. 636, *Transcript of Record*, vol. 1, p. 287.

[3] *Ibid.*

[4] T. T. Read, "The American Secret," *Atlantic Monthly*, March 1927, p. 291.

[5] This estimate appears to be conservative measured by other estimates available. Chester G. Gilbert and Joseph E. Pogue (in *America's Power Resources*, New York, the Century Co., 1921), assuming a power utilization of 150,000,000 horsepower and an equivalence of 20 man power for 1 horsepower, derived an estimate in 1921 of 30 units of mechanical energy for one unit of human energy. The ratio of 20 to 1 for Great Britain, referred to by the authors, if raised 1.6 times (see the comparison of British and American energy consumption above in the body of this report), gives a ratio for the United States of

States has, on the average, 35 invisible slaves working for him. The total energy population of the Nation is the equivalent of 4,700 million persons, but none of the 130 million living persons need be kept in a condition of servitude as thousands were in ancient Greece. Owing to the present dependence of accomplishment on resource energy, at the present time, economic opportunity for persons is closely associated with availability of such energy. Accordingly, one cannot visualize a democratic organization of society without widely distributed access to energy resources.

The Need for Coal Conservation

Most of the energy sources now being utilized are irreplaceable: once consumed or lost, they cannot be restored. They may, however, be utilized to more effective ends. Conservation of energy resources does not mean saving at a substantial sacrifice in current levels of productivity. As has been pointed out, "it does not mean locking things up. It means a wise use, the elimination of losses, and, where possible, the substitution of a more abundant material for a less abundant material."[6]

There are two principal reasons why coal is important in a consideration of the problem of conservation. First, in the United States coal provides more than half of the energy derived from minerals and water power. Second, coal resources, constituting an "abundant material" from the standpoint of energy supply, can be made available only under an increasing handicap as the better reserves become exhausted.

Coal deposits are gigantic storage batteries of solar energy, but the battery cannot be recharged when it is run down. Most of the coal deposits were formed 200 million to 250 million years ago, when the world was covered with much more dense vegetation than it has now. The idea of the origin of coal is not new. The view of Benjamin Franklin is of interest in this connection. "I am persuaded, as well as you," he stated, "that the sea coal has a vegetable origin, and that it has been formed from the surface of the earth; but as preceding convulsions of nature had served to bring it very deep in many places and covered it with many different strata, we are indebted to subsequent convulsions for having brought within our view the extremities of its veins, so as to lead us to penetrate the earth in search of it."[7]

The process of coal formation was exceedingly slow. George H. Ashley has estimated that it required 300 to 400 years under the most favorable conditions to form one foot of coal.[8] The Pittsburgh bed required not less than 2,700 years and may have taken 10,000 years. Yet this same authority estimates the life of the bed in Pennsylvania to be about 100 years additional at present rates of mining.[9]

The most essential constituent of coal—in fact, of all fuel-energy materials—is the carbon atom. Strange though it may seem, carbon is one of the rare elements of the world. It constitutes only four one-hundredths of 1 percent of the elements comprising the earth.[10] In the list of earthly elements carbon stands close to the very bottom in quantity.

Carbon is the indispensable element of all forms of life; it is the basis of the distinction between what is organic and what is inorganic. Coal was derived from plant life, most of it when the carbon dioxide in the air was much more plentiful than it is at present. "The particles of carbon dioxide have to be picked out one by one as the air passes in a tiny stream through the pores of the leaf, and the sensitive green-clad sentinels of chlorophyl watching at the gate can catch only three molecules out of ten thousand that defile them. If none of the carbon dioxide particles elude their vigilance, the yield, after sorting over a ton of air, is only eleven ounces and out of this only three ounces of carbon can be extracted."[11]

This segregation of carbon from the air is only the first step in the formation of coal. After the death of the vegetation the real work begins. The carbon content of coal is far more concentrated than that of vegetable debris; consequently, condensation must take place under pressure with the aid of humic acid. Geologists have estimated that five to eight feet of compact

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32 to 1. Per capita consumption of power in the United States has increased in the past 17 years, so that a current estimate of 35 to 1 is consistent with the earlier estimate.

R. B. Harper in a comparison of the approximate supplies of energy in 1930 ("Competition between Natural Gas and Coal," *Proceedings of the Third International Conference on Bituminous Coal*, 1931, vol. 1, p. 202) assigns 53.5 percent of the total energy supply to coal, 31.0 percent to oil and gas, 8.5 percent to water power, 6.0 percent to wood, 0.1 percent to wind, and only 0.9 percent to muscular power (man and work animals). This estimate ascribes much less than one one-hundredth of the energy supply to man power. An estimate of similar proportions is given by A. A. Potter and M. M. Samuels ("Power," *Technological Trends and National Policy*, National Resources Committee, June 1937, p. 263). The indefatigable nature of mechanical energy, of course, makes it more amenable than human energy to sustained application, and it is accordingly far superior in this respect. Greater precision also may be attained by machines.

[6] George H. Ashley, testimony in *Carter Coal* case, Supreme Court of the United States, October Term, 1935, No. 636, *Transcript of Record*, vol. 1, p. 530.

[7] Quoted by Lord Melchett, "Coal Problems in Perspective," *Proceedings, Second International Conference on Bituminous Coal*, Carnegie Institute of Technology, Pittsburgh, Pennsylvania, 1928, vol. I, p. 202.

[8] "General Information on Coal," *Bituminous Coal Fields of Pennsylvania*, Pennsylvania Geological Survey, Bulletin M–6, Part 1, 1928, pp. 45–46.

[9] Testimony in the *Carter Coal* case, *op. cit.* p. 533.

[10] Edwin E. Slosson, "The Synthetic Kingdom," *Proceedings, Second International Conference on Bituminous Coal*, Carnegie Institute of Technology, Pittsburgh, Pennsylvania, 1928, vol. I, p. 85.

[11] *Ibid.*, p. 97.

vegetable debris were required, when subjected to the compression of overlying strata, to form 1 foot of coal.[12] A coal bed 50 feet thick, such as the Mammoth Bed in the Schuylkill Field of the Pennsylvania anthracite region, required a deposit of compact vegetable debris almost 400 feet in depth.[13] Hundreds of forest jungles would have to grow and decay to produce a deposit so thick and so rich in carbon. The difficulty of reproducing a forest under present-day conditions, not hundreds of times, but only once, is familiar to those interested in reforestation. Coal beds are being formed today in a few scattered places, but no one can afford to wait for the results.

Coal is one of the miracles of nature. It remains to be seen how successful man will be in performing a greater miracle by providing fuel through short-cut synthetic processes at a cost as low as that at which ready-made coal can be obtained. Up to the present time, nature is far in the lead. It must be remembered that improvements in short-cut methods must compete with new developments in coal use. The Nation's rich bonus of coal has given an impetus to technological advance in energy utilization.

The Growth of Coal Utilization

In 1793 the United States produced about 63,000 net tons of coal.[14] Approximately two-thirds of the production was in Pennsylvania and one-third in Virginia. Production of Pennsylvania anthracite was probably only 200 tons. In 1840, when the first census of coal output was taken by the Federal Government, coal production was 2,070,000 tons.[15] In 1860 it reached 14,610,000 tons. In each year from 1841 to 1869, except 1865, Pennsylvania anthracite production exceeded total bituminous coal production.[16] Before that period, and since, annual production of bituminous coal was the larger. Each year prior to 1873, the United States imported more coal than it exported. In subsequent years, there has usually been a considerable export balance. The largest annual coal production on record was in 1918, when 678,212,000 tons were mined. By comparison, output in 1929 was 608,817,000 tons: in 1937, 494,311,000 tons. The growth of coal production since 1840 is shown in figure 1.

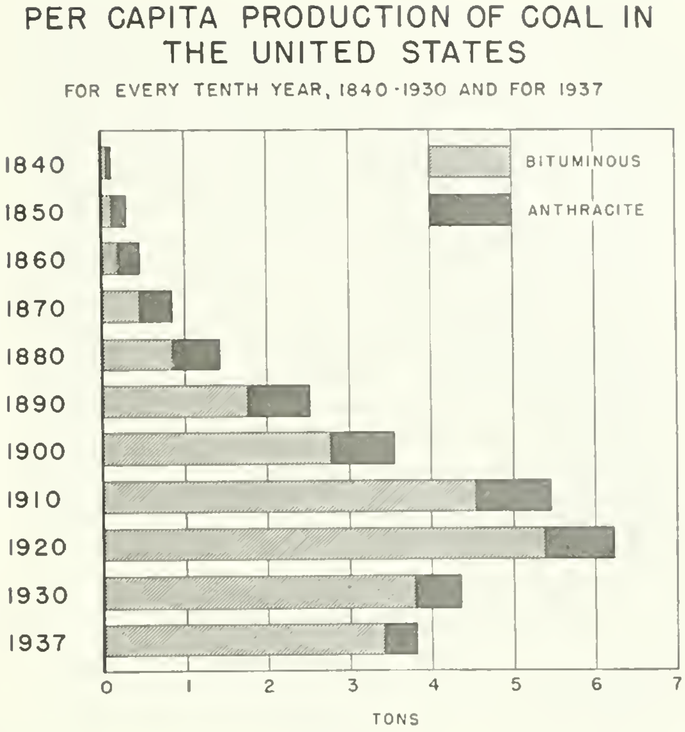

FIGURE 1.

The first hundred years of the Nation was a period of rapidly growing dependence on coal. At the outset, water power, wind power, wood, and work animals provided most of the energy to supplement human energy. Coal consumption began to expand rapidly during the 1830's and 1840's in connection with the application of steam to railroad and water transportation.

At the beginning of the current century, coal (anthracite and bituminous) contributed 89 percent of the energy derived from mineral fuels (coal, oil, and gas) and water power.[17] About this time, coal probably reached peak importance in the share of total energy it provided.[18] This statement does not mean, however, that the volume of coal energy ceased to grow after

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[12] *The Story of Anthracite,* prepared and published by the Hudson Coal Co., 1932, p. 2.

[13] *Ibid.*

[14] Howard N. Eavenson, *The Pittsburgh Coal Bed, Its Early History and Development,* The American Institute of Mining and Metallurgical Engineers, New York, 1938, table 1 (in pocket of back cover). A high degree of accuracy cannot be claimed for the data prior to 1840, but they suggest roughly the volume of production.

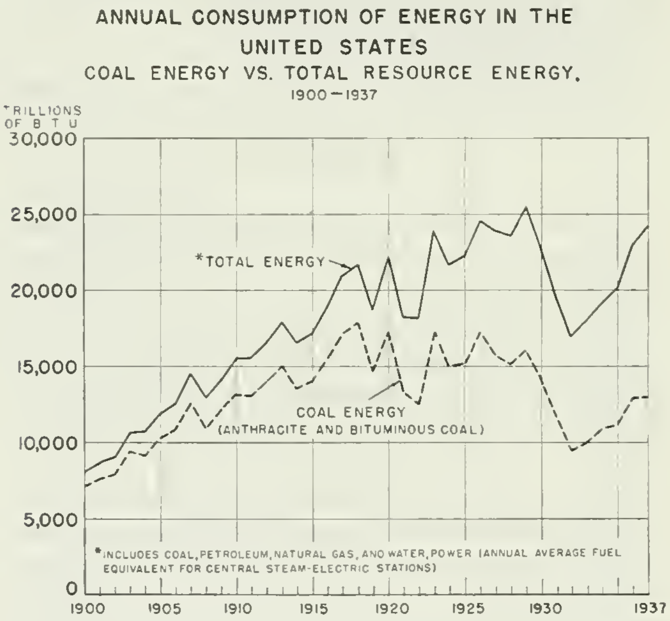
[15] United States Bureau of Mines, *Mineral Resources of the United States, 1923,* pt. II, p. 549.

[16] Eavenson, *loc. cit.*

[17] Water power is taken at the prevailing central station equivalent for the year.

[18] It is known that coal was relatively less important in the total for mineral fuels and water power in 1889 than in 1900. For much earlier years, such sources as wood and wind power for vessels and mills, not included in the data, as well as water power, probably were larger percentages of the total. A study by the United States Bureau of Mines of energy consumed in 1923 indicated that 6 percent was derived from wood fuel, 0.1 percent from windmills, 3 percent from work animals, 4 percent from water power, 22 percent from oil and gas, and about 65 percent from coal. The smallness of the percentages for wood, wind, and work animals suggests that they could not have been determining factors except in a much earlier period when coal constituted a considerably less important source. Energy represented in coal was 17,331 trillion B. t. u. in 1923, but only 7,123 trillion in 1900, and 3,746 trillion in 1889. See *Mineral Resources in the United States, 1927,* pt. II, p. 405; also H. M. Hoar, *The Coal Industry of the World,* Trade Promotion Series No. 105, 1930, U. S. Bureau of Foreign and Domestic Commerce, pp. 32–34.

1900. On the contrary, it increased from 7.1 quadrillion British thermal units[19] in 1900 to 17.9 quadrillion British thermal units in 1918 (fig. 2). The latter record has not been surpassed, and it is evident that the coal industry has been losing ground in most of the post-war period. Despite the peak of coal consumption in 1918, coal in that year supplied 82 percent of the total energy derived from minerals and water power, as contrasted with 89 percent in 1900. By 1929 the percentage was reduced to 63 and by 1937 to 54. Since 1900 water power has supplied approximately a constant percentage of the total energy, being in most years a little more than 3 percent.[20] The outstanding gain has been shown by petroleum and natural gas, which increased their share from 8 percent in 1900 to 43 percent in 1937.


ANNUAL CONSUMPTION OF ENERGY IN THE UNITED STATES
COAL ENERGY VS. TOTAL RESOURCE ENERGY,
1900—1937

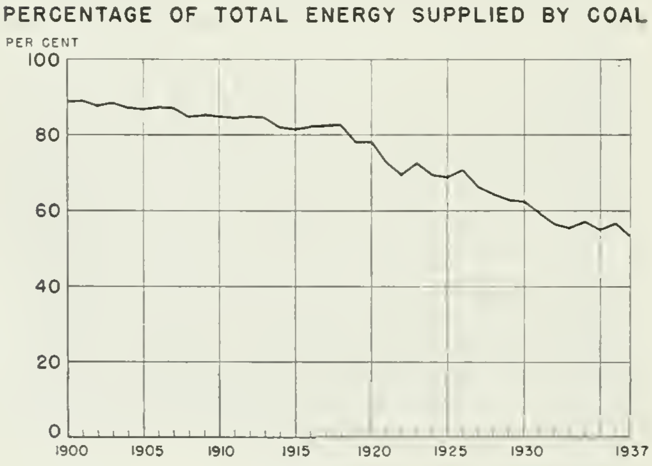

PERCENTAGE OF TOTAL ENERGY SUPPLIED BY COAL

FIGURE 2.

The coal industry, however, is not on the way to extinction. Less abundance of petroleum and natural gas resources than of coal resources will, in the course of time, bring about a recovery of the coal industry coupled with a decline of oil and gas.

The Importance of the Coal-Mining Industry

A consideration of coal merely as a source of energy is inadequate. It should not be overlooked that coal mining is one of the Nation's leading industries. Any action toward it will affect a large segment of economic life. Coal-energy policies must be shaped with this fact in mind.

The importance of coal-mining activity in the United States was indicated in a paper on coal conservation submitted to the Third World Power Conference by George S. Rice, A. C. Fieldner, and F. G. Tryon. "The annual value of bituminous coal produced in the five largest states exceeds the entire national output of gold, silver, copper, lead, and zinc, with aluminum thrown in for good measure. In West Virginia the number of men supported by the mines far exceeds the total employed in manufacturing industry, and in Kentucky it is not far behind. In Pennsylvania the soft-coal mines employ more men than does the steel industry, and in Illinois they employ about twice the number engaged in meat packing. Even in Ohio, which ranks far below the other states mentioned as a coal producer, the bituminous mines provide employment for more workers than do all the gold and silver mines of the country."[21] It may be observed also that the value at the mine of Pennsylvania anthracite usually far exceeds the value of gold and silver produced in continental United States.

The magnitude of the coal tonnage and coal energy produced in years of active mining has been shown in a comparison made by the famous scientist, Charles P. Steinmetz. If the coal produced in one year in the United States were to be used as building material, there would be a quantity sufficient to build a wall like the Chinese Wall, one of the great wonders of the world, all around the United States. The chemical energy contained in that quantity of coal would lift the wall 200 miles, or more than one million feet, high.[22]

In 1929 the average number of men employed at operating mines (anthracite and bituminous) was

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[19] A British thermal unit, abbreviated B. t. u., is the heat required to raise the temperature of 1 pound of water 1° F.

[20] Energy supplied by water power is calculated on the basis of the annual average coal consumption per kilowatt-hour for fuel-generated electric power.

[21] "Conservation of Coal Resources," *Third World Power Conference*, 1936, sec. IV, Paper No. 11, Washington, D. C., pp. 33–34.

[22] Quoted in Gilbert and Pogue, *op. cit.*, p. 31.

654,494, and in 1937 it was 585,500, whereas in 1923 there were 862.536 employed.[23] The value at the mine of the coal produced was $1,338,000,000 in 1929,[24] and about $960,000,000 in 1937.[25] Investment in coal mining runs into billions of dollars. The coal industry is a large consumer of power for the operation of its mines and collieries. It spends millions of dollars annually for machinery, equipment, and tools, and for timber to support the mine roofs.[26] About 60 percent of the mine dollar is spent for wages. Coal mining is the sole support of many communities and a heavy contributor in others. Whatever happens to the industry, therefore, is certain to affect directly the welfare of many people.

The Relationship of the Coal-Mining Industry to Transportation

It is often mentioned that the average cost of transportation of coal is as large as the average cost of mining. Normally, 85 to 90 percent of the bituminous coal produced is loaded at mines for shipment by rail (fig. 3); [27] some of this coal is later trans-shipped by water. The remaining 10 to 15 percent is originally shipped by water, by truck, or by wagon, loaded at the mine tipple for locomotive fuel, sold locally to mine employees, or consumed at the mine. In the anthracite industry, probably an even greater percentage of the total is shipped by rail.[28] In good years, coal constitutes 35 percent of the total railroad freight tonnage, and it provides 23 percent of the railroad freight revenue. No other commodity or class of commodities bulks as large as coal from the standpoint either of tonnage or of revenue. Total railroad freight revenue from

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[23] *Mineral Resources of the United States, 1930,* pt. II, p. 651; *Minerals Yearbook, 1938,* p. 693. The 1937 figure is preliminary.

[24] *Mineral Resources of the United States, 1930,* pt. II, p. 614.

[25] According to calculations of the National Bituminous Coal Commission, the value of bituminous coal and lignite was $859,000,000 in 1937. This figure includes an average of about 11 cents per ton selling expense which must be deducted to make the value figure comparable with that of 1929. The value of anthracite in 1937 ($197,599,000) is given in *Minerals Yearbook, 1938,* p. 748.

[26] In 1929 expenditures for fuel and purchased electrical energy were $52,000,000 and for supplies, $150,000,000. U. S. Bureau of Census, *Mines and Quarries:* 1929, p. 254.

[27] See *Minerals Yearbook, 1938,* p. 694.

[28] Lack of data for "bootleg mining" in the anthracite region introduces uncertainty regarding the exact proportions.

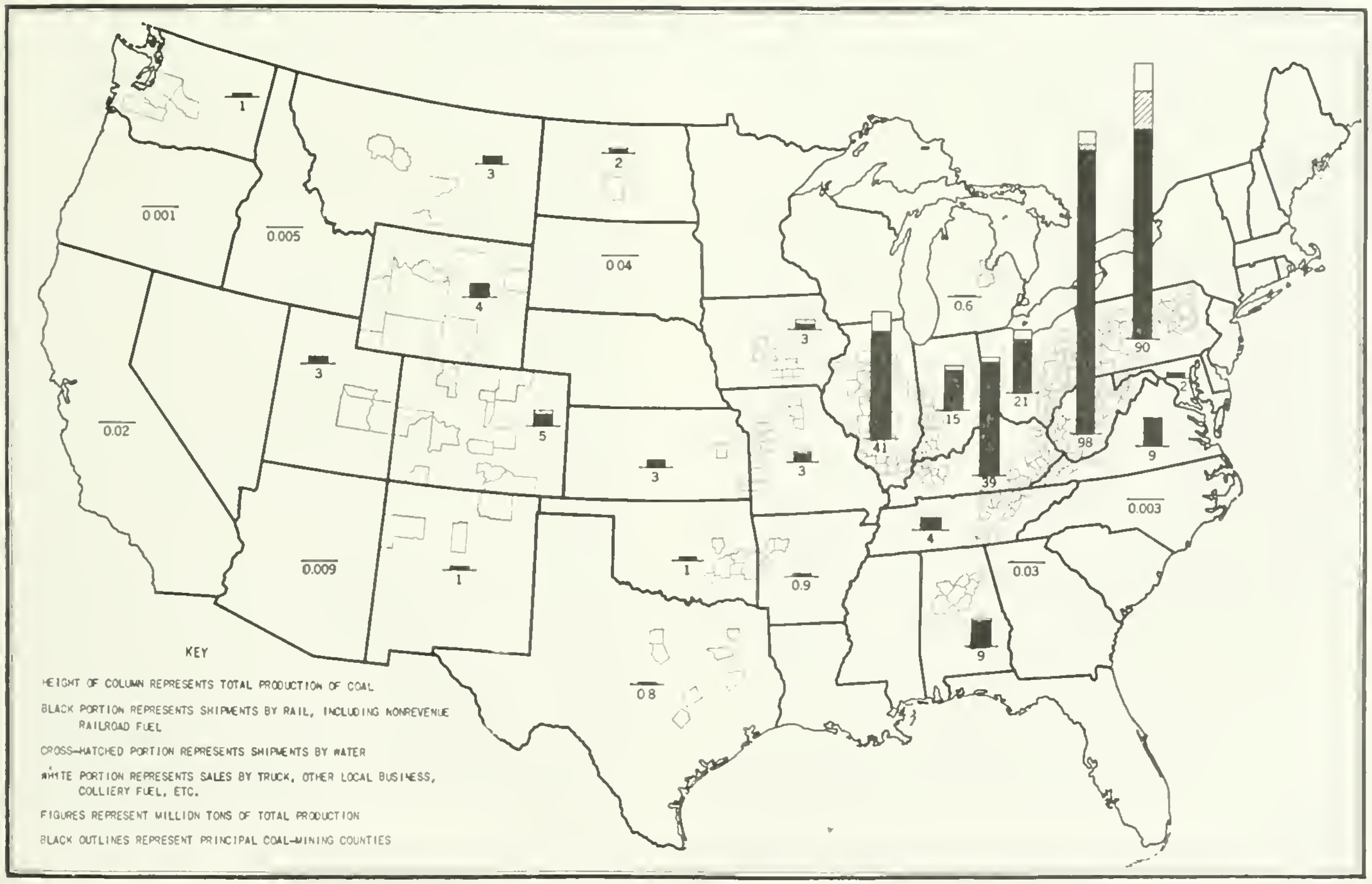
1
3
2
0.001
0.005
0.04
4
0.6
3
90
3
5
21
2
0.02
15
98
41
3
3
39
9
0.003
4
0.009
1
1
0.9
0.03
9
0.8
KEY
HEIGHT OF COLUMN REPRESENTS TOTAL PRODUCTION OF COAL
BLACK PORTION REPRESENTS SHIPMENTS BY RAIL, INCLUDING NONREVENUE RAILROAD FUEL
CROSS-HATCHED PORTION REPRESENTS SHIPMENTS BY WATER
WHITE PORTION REPRESENTS SALES BY TRUCK, OTHER LOCAL BUSINESS, COLLIERY FUEL, ETC.
FIGURES REPRESENT MILLION TONS OF TOTAL PRODUCTION
BLACK OUTLINES REPRESENT PRINCIPAL COAL-MINING COUNTIES

FIGURE 3.—Production of Bituminous Coal in Each State and Proportion Shipped by Rail and by Water, 1934. (Reproduced from *Minerals Yearbook, 1936,* p. 556.)

coal for Class I railroads[29] amounted to $733,000,000 in 1937. To this figure must be added a sizable, but indeterminate, amount for the cost of hauling coal for use by railroads themselves (deadhead coal) and for revenue from truck, wagon, river, lake, and ocean transportation of coal, as well as a small amount for transportation by Class II and Class III railroads, to arrive at the total transportation bill for coal. The total mine value of the coal, it was observed earlier, was about $960,000,000 in 1937. Forty-eight percent of the railroad operating revenue dollar in 1937 was compensation to employees.[30] Owing to the bulkiness of coal, perhaps a smaller proportion of the revenue from coal transportation should be allocated to employment on coal haulage. As a generalization, it may be said that the mine value of coal and the total cost of coal transportation are approximately equal, but labor cost is probably somewhat larger for coal mining than for coal transportation.

The Importance of Coal-Marketing Activity

The marketing of coal is so commonly associated with that of other products, such as coke, fuel oil, ice, and building materials, that the *Census of Business* does not give data specifically on coal distribution. The classes of business for which reports are presented. however, throw some light on the importance of coal as an item of trade activity. The *1935 Census of Wholesale Distribution* lists 773 full-service and limited-function coal and coke wholesalers with net sales of $369,000,000; coal and coke sales branches (with or without stocks) numbering 16 and having net sales of $20,000,000; agents and brokers of coal and coke operating in 440 establishments and doing a net sales volume of $427.000.000.[31] Less is known about retailing of coal than about wholesaling. In the *Census of Retail Distribution*, no single item given is even approximately indicative of the volume of coal business at retail. Probably a large share of the net sales of $841,000,000 by 35,176 fuel and ice dealers in 1935 consisted of coal sales.[32] To that amount, however, would have to be added coal sales by lumber dealers and other dealers in building materials, by established coal dealers, by "snowbirds",[33] and by other types of concerns. Altogether more than 30,000,000 tons of anthracite and between 56,000,000 and 77,000,000 tons of bituminous coal were sold to domestic (household) consumers in 1936.[34]

Some information reflecting the cost of coal wholesaling and retailing was gathered by the United States Coal Commission and published in its report of 1925. The average gross margin at wholesale (the difference between the cost of the coal to the dealer and his selling price) was 16 cents per ton for bituminous coal and 23.3 cents per ton for anthracite in November 1921 (data for 1922 are not used because of the shortage of supply that year).[35] The margin for the two kinds of coal combined increased from 9.4 cents in 1913 to 19 cents in 1921. The American Wholesale Coal Association advocated a gross margin of 8 percent on the selling price, but this was thought by the Coal Commission to be excessive. In view of the severe competition in coal wholesaling since 1921, a smaller percentage undoubtedly has applied.

The average gross margin of retailers was $2.51 in 1921 for anthracite and bituminous coal combined. This figure represents a considerable increase over the margin of $1.89 recorded for 1918. Information collected by the Commission shows that the margins vary according to the season. They are larger in the winter than in the summer, larger for prepared sizes of coal than for run-of-mine coal, larger in populous cities than in small centers, and larger for anthracite than for bituminous coal. No doubt retail margins, like wholesale margins, have decreased somewhat since 1921, although demand for better preparation and handling has tended to check the decline.

In the marketing of coal, the relatively large volume distributed by direct methods is a characteristic feature. The *Census of Mines and Quarries* for 1929 indicates the amount of coal distributed through each marketing channel. For the bituminous coal industry, 60.1 percent of the tonnage was sold directly to consumers by main offices (including retailers invoiced by main offices) or branch sales offices of mining companies.[36] The proportion of anthracite sold by the same direct channels was 63.6 percent. There were also direct deliveries by "captive mines," that is, mines owned by industrial consumers, in large part, steel companies. These deliveries accounted for 21.3 percent of the tonnage of bituminous coal marketed in 1929, but for only 1.0 percent of the anthracite marketings. Only 18.2

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[29] Railroads with annual operating revenues each of more than $1,000,000 (during the year in which the classification was made). These Class I railroads in 1937 accounted for 98.57 percent of the total railroad freight revenue (line haul) of Class I, II, and III railroads.

[30] Calculated from Association of American Railroads, *Statistics of Railways of Class I, United States, 1926–1937*, Washington D. C., September 1938, sheets 1 and 3.

[31] *Census of Business: 1935, Wholesale Distribution*, vol. VIII, *Commodity Sales*, pp. 17–18.

[32] Data from *Census of Business: 1935, Retail Distribution, United States Summary*, p. 15.

[33] Concerns that undertake to sell coal temporarily when a seasonal or other favorable opportunity arises.

[34] *Minerals Yearbook, 1938*, p. 758.

[35] All data on margins are from the *Report of the United States Coal Commission*, pt. II, Washington, D. C., 1925, pp. 701–836.

[36] Bureau of the Census, *Mines and Quarries: 1929*, p. 271.

percent of the bituminous coal and 35.1 percent of the anthracite went to independent wholesalers, jobbers, and nonaffiliated agents. A minor proportion, of course, was consumed at the mines for power and heat.

The Nation's Coal Bill

The Nation's coal bill may be assumed to include all expenditures for coal mining, transportation, and distribution; that is, all items from the initial stage of production until the coal is transmitted to the final consumer. It excludes expenses, such as those for storage and handling, incurred by the final consumer (these being impossible to estimate) and expenses for conversion into coke or other fuels. So defined, the Nation's coal bill is estimated to have amounted in 1929 to $2,950,000,000.[37] Somewhat less complete data for 1936 indicate an expenditure for that year of $2.380,000.000.

Expenditures for coal-mining activity in 1929 were $1,340,000,000, or 45 percent as much as the total coal bill; freight paid to Class I railroads was $1,100,000,000, or 37 percent. Analogous figures for 1936 are $990,000,000, or 42 percent, for mining; $950,000,000, or 40 percent, for railroad revenue freight. The remaining proportions of the total bill may be allocated in the main to other marketing work, including nonrevenue railroad haulage, water transportation, trucking, and wagon haulage. A word of caution, however, should be interposed. Mine realization and freight revenue are closely correlated with production, whereas the total coal bill is the cost of coal to consumers. In 1929, because of the net effect of foreign trade and changes in stocks, output and shipment of coal were larger than consumption.

The Importance of Coal to Consuming Industries

Modern industry cannot operate without consumption of large quantities of energy. The great nations of the world today are those that make wide use of energy resources. Probably no other factor accounts so much for the leading position of the United States. It is almost a foregone conclusion that a decline of energy consumption will lead to economic retrogression, no matter how favorable other factors may be.

The cost of a unit of resource energy is only a fraction as much as that of human energy. The outlay necessary to maintain four and one-half billion extra persons in the United States, a number that might be required to replace the volume of resource energy now used, would be unbelievably large even at a bare subsistence level. At a yearly wage of only $200 per capita, for example, the outlay would be 900 billion dollars, or almost 13 times the national income in 1937.[38] Such a multitude of living energy servants would be impossible to maintain, and, even if they could be supported, most of their energy would be diverted to producing food, clothing, and shelter for subsistence.

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[37] Coal from captive mines and coal used at mines for power and heat involve little if any expense for marketing other than transportation. Wholesale costs of selling on 412 million tons of bituminous coal and 61 million tons of anthracite are estimated at $66,000,000. Retail costs of selling on 90 million tons of bituminous coal and 54 million tons of anthracite are estimated at $346,000,000. These wholesale and retail items include some expenditure for transportation. A residual item of $98,000,000 is included in the total coal bill to adjust for imports, exports, change of known stocks, and to allow for miscellaneous costs such as those for handling at docks, storage at terminals, and transportation not elsewhere classified. There were, for example, 38 million tons shipped on the Great Lakes, 35 million tons, excluding exports, shipped at Atlantic tidewater, and 21 million tons shipped on rivers. Trucking, not included as selling cost above, also was important.

Another way of arriving at an estimate of the total coal bill is by summation of expenditures by various classes of coal consumers. Outlays for coal by manufacturing plants in 1929 were $720,100.000 for 204 million tons of bituminous coal, and $43,500,000 for 10,400,000 tons of Pennsylvania anthracite. Railroads spent $314,600,000 for 131,100,000 tons of bituminous coal, and $5,300,000 for 1,600,000 tons of anthracite. To the cost of coal to railroads there must be added an allowance for costs of transporting coal consumed by the originating line. A total coal bill for the railroads may be conservatively estimated at $363,000,000 for bituminous coal and $7,000,000 for anthracite. Domestic (household) consumption of bituminous coal of about 70 million tons multiplied by $8.85 per ton, the average price in 38 cities, is $619,500,000. Shipments of domestic sizes (mostly stove and chestnut) of anthracite totaled 46,100,000 tons. Data for four cities on the retail price of anthracite and for sales realizations on breaker shipments indicate an average retail price in 1929 of $14 per ton as a reasonable figure. The total bill for household sizes of anthracite then is $645,400,000; some of this, of course, was for nonresidential use. Electric power plants consumed 42,800,000 tons of bituminous coal at an estimated cost of $145,000,000, and 2,200,000 tons of anthracite at a cost of roughly $8,000,000. Mine-mouth use (for beehive coke, local sales, and mine fuel) consumed 38 million tons of bituminous coal. At the average mine value, this coal would be valued at $67,600,000. A total of 8,500,000 tons of anthracite was used at the mine, and most of this was for steam-raising purposes. On the basis of average realization ($2.28 per net ton) for steam sizes, a valuation of $19,400,000 is obtained. These calculations leave 33,700,000 tons of bituminous coal consumed in the United States unaccounted for. No very reliable estimate of the valuation per ton of this coal can be made, but, if the average mine value and the average railroad freight plus some allowance for selling costs and other transportation costs be taken as a guide, a figure of $190,000,000 seems reasonable. A total bill of $2,105,200,000 for bituminous coal is obtained. The tonnage of anthracite listed in the calculations is about equal to anthracite production in Pennsylvania, but the United States had an import balance of 2,900,000 tons of anthracite, nearly all of it used as a high-grade household fuel. This tonnage involves a cost of perhaps $10,600,000. The estimated total for anthracite is $763,900,000, and for anthracite and bituminous coal combined, $2,869,100,000. This figure is $80,900.000 below that actually used, but there are numerous miscellaneous items not covered in the enumerated classes.

In all these estimates it should be observed that the aim is to arrive at the total cost to consumers. The estimates will not agree with those based on production, because of exports, imports, and changes in stocks. The available data omit, in most instances, coal obtained from the small truck and wagon mines.

For sources of information, see: *Census of Manufactures: 1929*, p. 161; Association of American Railroads, *Statistics of Railways of Class I, 1926–34*, sheet 11; *Mineral Resources of the United States, 1930*, pt. II, especially pp. 617, 675, and 727–33; *Minerals Yearbook, 1937*, p. 794; *Minerals Yearbook, 1938*, p. 697; census of *Central Electric Light and Power Stations, 1927; Report of the United States Coal Commission, 1925*, pt. II, pp. 701–833; census of *Mines and Quarries: 1929*, pp. 253–287.

[38] See Robert R. Nathan, "National Income in 1937 Largest Since 1929," *Survey of Current Business*, June 1938, pp. 12 and 13.

Only a small proportion of our energy resources, on the other hand, are consumed in making the energy materials available for use.

The Nation's coal bill is only 4 percent of the national income, even though coal supplies more than half of the total resource energy consumed. Although resource energy is the foundation of our industrial economy, the cost of fuel is usually a small proportion of total cost. In 1929 expenditures of manufacturing industries for fuel and purchased power were only 13 percent of their total expenses for salaries and wages, and expenditures for coal were only 5 percent. Railroads are leading consumers of coal and oil, yet only 9 percent of their operating expenses in 1937 were for fuel and only 7 percent for coal. Electric power plants are purveyors of energy, but fuel outlays constituted in 1932 not more than 20 percent of the total operating expenses of fuel-using commercial and municipal plants. Among ultimate consumers, fuel (including light) cost is normally only 6 percent of the total budget, and coal cost is but part of the total fuel cost. These figures attest the great advantage inherent in the utilization of resource energy.

Energy production, of course, is not itself the ultimate goal of society, but it is a means of providing desired goods and services. One has to distinguish between the cost of obtaining energy and the cost of obtaining by alternative means what energy can produce. Measured by the first standard, thanks in large part to concentrated mineral deposits, resource energy is not the most conspicuous item in the budget. Measured by the second standard, however, resource energy is the main pillar, without which the industrial system would collapse. Obviously, the full importance of the resource energy supply, and in particular of the leading source, coal, can never be measured in dollars and cents.

CHAPTER 2.—COAL RESOURCES AND THEIR RATE OF DEPLETION

The Problem of Estimating Minable Reserves

The Nation's coal reserves are extensive but highly variable in quality and accessibility (fig. 4). Coal, some of it low-rank or difficult to mine, is sufficiently plentiful to last for many generations if reasonable care is taken to avoid wastes in mining and utilization. Thirty-one states of the Union are endowed with reserves classified by the United States Geological Survey as minable reserves, although, in 1937, four-fifths of the production was in Pennsylvania, Ohio, West Virginia, Kentucky, and Illinois. Regional concentration of reserves exists in such degree that distribution of coal to the market is a serious problem. Total transportation costs are about as large as mining costs. This lack of uniform occurrence, as well as differences in wage scales and in effort required to mine the coal, accounts for marked variation in coal prices in consuming areas. The chief practical question of reserves is whether coal is obtainable with the expenditure of little energy or whether it can be mined and delivered only at high cost. For the most part, the Nation's best coal is being depleted either by use or by loss. A growing handicap, tending to cancel gains resulting from improvement of production techniques, is the prospect for the future, as the process of depletion of better ranks and more accessible beds of coal proceeds.

Exhaustion in local areas, often leaving entire communities stranded, already has become a problem. On the other hand, there is no prospect for the near-term future of complete depletion of the aggregate coal supply. Therefore, attention is focused primarily on what exhaustion of the principal beds means in terms of the growing handicap of reduced quality and increasing inaccessibility of coal.

Every estimate of the life expectancy of coal reserves must take into account, as one branch of the problem, the quantity, character, and occurrence of coal deposits, and, as the other, the rate of use and loss.

Nature has not made available for mining all the coal originally deposited. Long before settlement of the continent took place, billions of tons of coal were lost by erosion. Valleys were cut through coal-bearing strata, and the coal was carried away. Erosion is said to have destroyed 95 percent of some of the anthracite beds.[1] Throughout most of the coal regions of the country, outcrops of coal beds may be seen in river valleys. These outcrops make possible the low-cost drift mining (mining by tunneling into the outcrop at the side of a hill) so prevalent today. A second factor in loss of coal is the faulting, folding, and pitching of the beds in some areas, making it unprofitable to undertake mining operations. Changes of this character have occurred, for example, in the Pennsylvania anthracite region. A third factor, one of minor importance, is deterioration of coal by weathering of exposed or shallow beds. A further factor is the occurrence of coal in beds too thin or too deep to be mined profitably even at high prices. The quantity of coal in this category is enormous, although its existence has no practical bearing on the resources problem.

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[1] *The Story of Anthracite,* prepared and published by the Hudson Coal Co., 1932, p. 5.

The processes of destruction by the elements are currently at work. Their action, nevertheless, is so slow that they may be disregarded in considering what has happened to the coal reserves since the beginning of mining and what is in prospect for their future. Far more important is the depletion of coal reserves by mining activity.

Reserves Originally Available

Total reserves of coal in the United States in minable beds are estimated to have been at the beginning of mining a little more than three trillion tons. The latest (1928) figure given by Marius R. Campbell, of the United States Geological Survey, is 3,214,898,600,000 net tons.[2] This estimate is a useful summary indicator of the magnitude of the reserves, although it needs to be interpreted with caution. It includes, on a tonnage basis, coals ranging from the highest rank to the lowest rank—anthracite to lignite. Coals with an ash content up to 30 percent are included, even though at the present time an ash content half as great as that upper percentage sets the approximate limit for mining. A similar qualification applies to thickness and depth of the beds. In the Campbell estimate, 14 inches was adopted as the minimum thickness for bituminous coals and anthracite, two feet for subbituminous coals, and three feet for lignite. In practice, not many of the subbituminous and lignite deposits running to twice the minimum thickness adopted for the estimate are being mined in volume, and there is only a small tonnage of the higher rank coals taken from beds less than two and one-half feet thick. There is some strip mining of beds 14 to 22 inches thick in Missouri, Kansas, Arkansas, and Oklahoma, and some mining, by the longwall system, of beds 17 to 24 inches thick in Missouri, Kansas, and Arkansas.[3] Nevertheless, in Pennsylvania and West Virginia, which account for about half of the national total bituminous coal output, the bulk of the production is concentrated in beds of

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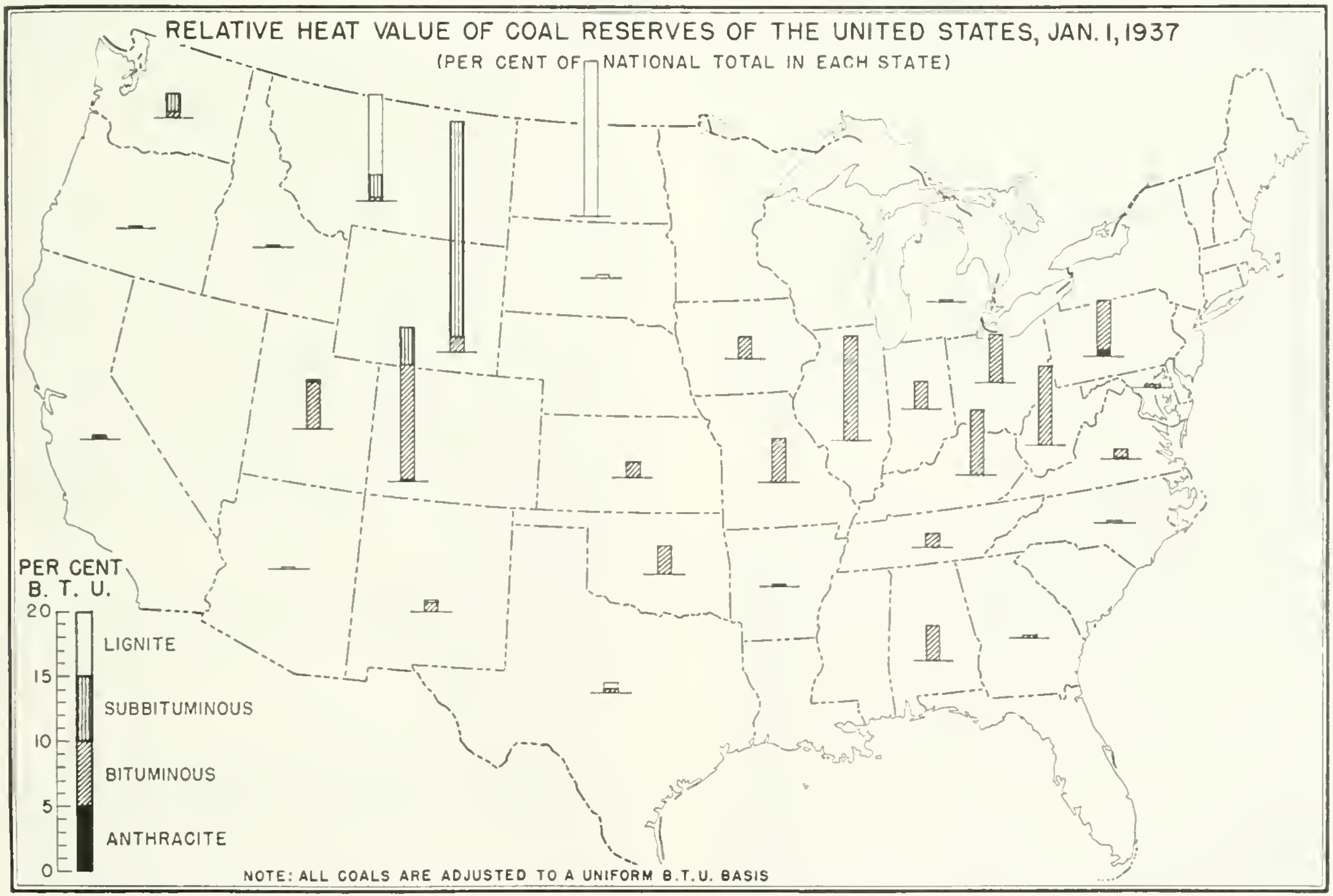
[2] Campbell, *Coal Resources of the United States,* United States Geological Survey (a 6-page multigraphed report).

[3] *Cf.* Toenges, Albert L., and Anderson, Robert L., *Some Aspects of Strip Mining of Bituminous Coal in Central and South Central States,* U. S. Bureau of Mines, Information Circular 6959, October 1937; also *Coal Mine Mechanization Yearbook, 1938* (The American Mining Congress, Washington, D. C.), pp. 157–168.



RELATIVE HEAT VALUE OF COAL RESERVES OF THE UNITED STATES, JAN. 1, 1937

(PER CENT OF NATIONAL TOTAL IN EACH STATE)

NOTE: ALL COALS ARE ADJUSTED TO A UNIFORM B.T.U. BASIS

Prepared in office of the National Resources Committee

FIGURE 4.

four feet or more thickness. The estimate of resources includes beds as much as 3,000 feet below the surface, whereas coal companies in this country seldom mine beds more than several hundred feet down, and a high percentage of the mines today do not require the sinking of vertical shafts to reach the coal, less expensive horizontal or sloping "tunnels" being sufficient.[4] Topography, of course, is an important factor in determining where coal is mined. Some foreign countries with small coal reserves operate coal mines at depths of more than 3,500 feet.[5] Under the pressure of necessity, deeper beds in the United States could be worked, but, of course, at extremely high cost. It is estimated that an additional 604,000,000,000 tons of coal lie at a depth of from 3,000 to 6,000 feet.[6] This amount added to the reserves at shallower depth gives a total of 3,818,898,600,000 tons at the outset of mining in beds of workable thickness. Nevertheless, owing to the unlikelihood of coal mining at depths of 3,000 feet or more for many generations, it appears advisable to revert to the previous estimate of three and two-tenths trillion tons as the basic figure for the bounds of available reserves. This figure does not include reserves in any of the United States' possessions. Alaska is known to have extensive reserves ranging in rank from lignite to anthracite.[7] Coal beds exist along the coast as well as in the interior of Alaska, but additional prospecting work will have to be done before the tonnage of recoverable coal can be estimated. Reserves in other possessions are probably negligible. Conditions on the island possessions generally have been unfavorable to the formation of coal. Hawaii, for example, although an important fueling station for vessels, has no native coal resources, the bulk of the coal in the past having been supplied by Japan, Australia, and Great Britain [8]—an indication of the dearth of our continental supply along the Pacific Coast and of the potential importance of the Alaskan deposits.

How Much Coal Remains?

Part of the Nation's coal reserves has been consumed, lost in mining, or otherwise made unavailable since coal began to be used as fuel. Fortunately, mining activity has made only slight inroads into aggregate reserves, even though it has eliminated some of the most valuable deposits. Only about 1 percent of the available tonnage of reserves has been removed or lost since mining began. This change in coal reserves is shown in a special tabulation prepared by T. A. Hendricks of the United States Geological Survey.[9] The calculated reduction of reserves attributable to production and losses in mining, handling, and preparation in the entire period of mining up to January 1, 1937, is 34,133,350,000 tons for all ranks of coal combined. For purposes of this estimate, a loss of 34.7 percent of reserves mined is assumed,[10] this percentage having been determined in a study by the United States Coal Commission and the United States Bureau of Mines of the amount and nature of losses in mining bituminous coal during 1923 in eastern United States.[11] This percentage, accepted as being typical of the industry as a whole, indicates that about one-half ton of coal is lost for each ton removed in mining. Deducting this proportion for depletion from the initially available reserves as estimated by Campbell, one obtains a total reserve remaining at the beginning of 1937 of about 3,180,765,250,000 net tons. Production and loss since then would make only an insignificant relative reduction of the total. The current reserve supply may be designated in round numbers as 3,200 billion tons. Insofar as one may profitably use a summary compilation in considering the complex problem of reserves, this figure will serve adequately the purpose of showing the sheer bulk of coal in minable beds.

All the 3,200 billion tons in minable beds, however, will not be taken from the ground and made available for consumption; avoidable and unavoidable losses in mining, handling, and preparation of the coal have to be deducted to arrive at the total reserve of consumable coal. With present rates of loss in mining and distribution, not more than two trillion tons of the estimated reserves ever will be put to productive use. Full recovery, although closely approached in some strip mines, ordinarily is impossible of achievement even under the best practicable mining methods. Billions of tons, nevertheless, can be added to the consumable supply by the adoption of less wasteful methods of exploitation.

This problem of waste elimination is considered at a later point. For the present, reserves are considered from the standpoint of the actual performance record of the industry.

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[4] In West Virginia, for example, slope and drift mines outnumber shaft mines by more than 10 to 1. See *Annual Report of the Department of Mines, West Virginia, 1936,* pp. 54–90.

[5] Campbell, *op. cit.*

[6] M. R. Campbell, *Coal Fields of the United States,* United States Geological Survey Professional Paper 100A, 1922, table on insert sheet after page 24.

[7] *Regional Planning, Part VII, Alaska—Its Resources and Development,* National Resources Committee, December 1937, p. 210.

[8] H. M. Hoar, *The Coal Industry of the World,* United States Department of Commerce, Trade Promotion Series, No. 105, 1930, p. 240.

[9] Pt. two, sec. I, ch. 1, this volume.

[10] Campbell, in earlier estimates of available resources, applied a loss factor of 30 percent to production. A higher proportion, such as that used by Hendricks, appears advisable. In the early days of the coal industry, wastes were much larger than in recent years. A small part of the coal previously discarded may be retrieved. In fact, this is now being done in the anthracite region. Second mining is also in progress in many bituminous coal fields close to centers of population. Part of the coal used in the City of Pittsburgh is obtained in this way.

[11] See table 5, in ch. 4, this section.

Have All the Resources of Coal Been Discovered?

Estimates of coal reserves would have limited meaning were there large undiscovered tonnages of coal in the ground. Additions to the known reserves might significantly affect reasoning with regard to the life of the coal deposits. Special uncertainty would be attached to regions at present assumed to be devoid of coal, later to be added to the list of regions having a native supply. Much depends on the nature and occurrence of deposits in determining whether an area can compete as a fuel producer or whether costs can be reduced enough to meet the present-day requirement of cheap fuel. Are all the coal fields of the United States known? How accurately have their limits been determined? The first question can be answered in the affirmative, insofar as fields of commercial interest are concerned. M. R. Campbell states that there are some small areas about which little information is available.[12] Estimates of their resources are little more than a guess. Owing to extensive field work in Federal and State geological surveys, however, most of the coal fields are well known. The occurrence of coal is easy to detect by the use of core drillings. In many areas, of course, outcrops give an obvious clue. The tendency of coal deposits to spread over comparatively wide expanses assures that not many important reserves will be overlooked entirely.

The question of accuracy of measurement cannot be answered so definitely. To estimate the tonnage of coal in a deposit, it is necessary to know both the specific gravity and the cubic content of the deposit. Recent determinations of the specific gravity of various kinds of coal indicate that the average used in the Campbell estimates (81.25 pounds per cubic foot) was too low, tending toward an understatement of the reserves. On the other hand, the measurements of cubic contents appear to exaggerate the real extent of the reserves. More interest centers on thick beds than on thin beds, and even the thicker portions of a given bed receive more attention than the thinner portions. Areas of thin beds are likely to be passed over, whereas those of thick beds will be measured with care and the measurements entered on the records. The use of the measured portions as a basis for estimating the contents of an entire coal area, of course, introduces a bias into the calculation. How much the exaggeration might be has not been ascertained. Recent studies [13] indicate that the overstatement may be considerable. Between 1912 and 1928 Campbell reduced his own estimate somewhat, as better measurements became available.

Comparison with Reserves in Foreign Countries

The problem of arriving at a meaningful and uniform basis for the estimation of coal reserves has been considered in the discussion of coal reserves in the United States. A comparison of reserves in the United States with foreign reserves encounters greater obstacles because of the difficulty of getting agreement on standards of measurement and on invariable application of those standards to all possible areas of coal occurrence. Fortunately, data available are sufficiently dependable to indicate the approximate proportions of the world's coal resources in the United States, comparisons among the commercially developed countries being the more reliable.

On the basis of the best information available at present, it appears that the United States (Alaska included) has approximately half of the total coal reserves of the world. Subsequent readjustments of the data for new discoveries in undeveloped regions and for reductions of reserves by mining, wastage, and unavoidable losses, as well as changes necessitated by more accurate measurement, probably will reduce somewhat the share recorded for the United States. In 1913 the Twelfth International Geological Congress conducted a world-wide survey of coal reserves. This survey remains today the basic source for comparable data on coal reserves in the various regions of the world, although, of course, there have been numerous changes of political boundaries and important resurveys of coal reserves, with various standards of measurement.[14] World coal reserves were estimated at 8,154 billion net tons. World production of coal for the period 1913–37 amounted to 36 billion net tons.[15] If this quantity, together with allowance for coal losses, be deducted from the 1913 figure on reserves, an estimate is obtained of about 8,100 billion net tons for reserves at the beginning of 1938.

Proportionate shares of various regions in the world total undoubtedly have not been disturbed enough since 1913 to make any appreciable change in the percentage of total coal recorded for those regions. The 1913 study, therefore, is indicative of the current distribution of reserves. It is estimated that the United States, including Alaska, has 52 percent of the world reserves; North America has 69 percent of the total, Europe 11 percent, Asia 17 percent, Oceania 2 percent, and Africa and South America combined only 1 percent. Data for South America are somewhat incomplete, but it is probably true that not more than 5 percent of the reserves are in the Southern Hemisphere. The United States has almost 5 times as much coal as Europe and 3 times as much as Asia. Our northern neighbor, Canada, has about 1½ times as much coal as Europe and almost as much as all Asia.

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[12] *Coal Resources of the United States, op. cit.*

[13] Referred to by George S. Rice, A. C. Fieldner, and F. G. Tryon, "Conservation of Coal Resources," *Third World Power Conference*, sec. IV, Paper No. 11, Washington, 1936, p. 3.

[14] It should be observed that the uniform standards adopted in the 1913 survey are not comparable as a rule with those adopted for other surveys. Comparisons should not be made without thorough investigation.

[15] Compiled from various issues of *Mineral Resources of the United States*, 1922–31, and *Minerals Yearbook*, 1932–38.

Of the world total reserves, only about 7 percent is anthracite and semianthracite, about 53 percent consists of bituminous coals, and the remaining 40 percent is low-rank coals classified as subbituminous or lignite. Coals of the United States do not, on the average, rank higher in quality than those in foreign countries. In fact, the supply of anthracite in this country is decidedly limited, being less than 4 percent of the total for the world. European Russia has twice as much anthracite and semianthracite as has the United States. Indo-China has a slightly larger supply than ours, according to the 1913 survey; China was thought to have many times as much, but the figures have been revised downward drastically. Recent evidence indicates that the reserves of anthracite there are somewhat more than twice as large as those in the United States.[16]

The United States has a relatively abundant reserve of low-rank coals. Its reserves of subbituminous coals and lignite are 62 percent of the world resources of the same rank coals. Of the higher rank bituminous coals, which now supply the bulk of the world's solid fuel requirements, the United States has half of the total. This evidence suggests that coals in this country are not far superior in quality to those in foreign nations. They appear, on the contrary, to average approximately the same, although the difficulty of maintaining a uniform classification among all countries makes a comparison of this nature uncertain. The great advantage of the United States lies in the volume and accessibility of its coal reserves. Even if only approximate accuracy of the coal-reserve data be assumed, one may state with confidence that given a per capita consumption of coal in foreign countries approaching that in the United States, exhaustion will be felt abroad long before it is felt here. The United States is undoubtedly in a relatively favorable position for continued liberal use of coal energy.

Prospects are not bright for the development of a large export market for American coals to any country except Canada. The principal reason for this is that the bulk of the domestic reserves lies a considerable distance inland. An overland haul, coupled with reloading on vessels, is a hurdle that American mining companies are not able to overcome to gain access to the international market in competition with mining companies in countries, such as England, Scotland, Belgium, and Australia, that draw their supplies from reserves close to the seacoast. European mines are likely also to have favorable ocean transportation rates. Among the major coal fields of the United States, only the anthracite reserves in Pennsylvania are near navigable streams leading directly to the ocean, but even the anthracite must be hauled some distance by rail to reach the head of navigation. The bulk of reserves is in the great Mississippi drainage basin, either on streams that are not navigable or on streams that lead to cheap ocean transportation only by long, circuitous routes. The reserves, being in the interior, have exerted a strong pull on industry to draw it to this section of the country rather than to scatter it along the periphery or to encourage industrial development in foreign lands. Coal being a bulky commodity, its transportation costs are a decisive element in determining what areas may gain access to the reserves. Shipment by water over natural waterways or developed streams is a relatively cheap means of transportation and is used wherever available. The Great Lakes and the Ohio, Kanawha, Monongahela, and Allegheny Rivers are vital connecting links between the coal fields and the coal markets. In the past these routes have directed heavy industries into the inland manufacturing belt. The focus of American industrialism, therefore, became one of regional concentration and comparative self-sufficiency instead of one of exchange of coal energy resources and of other commodities with foreign nations. Great Britain typifies the opposite type of development.

Water transportation of coal in the United States is used mainly in conjunction with Appalachian coal and undoubtedly accounts in no small measure for the growth of manufacturing in the northeastern states. On the other hand, billions of tons of reserves lie idle in the western part of the country for want of a market. The Appalachian reserves have been and continue to be much more indispensable to our economy than the reserves in the West (fig. 5).

In every area, the significance of coal reserves to industry depends on the commercial possibilities of bringing together coal energy and other resources. In this machine age, the combination of coal and iron is of leading importance. The United States has been able to maintain high productivity and a high standard of living because of this favorable opportunity for utilization of coal in the manufacture of producers' goods, as well as commodities used by ultimate consumers. In every region the significance of coal reserves depends as much on the possibilities of converting the coal to use as on the tonnage in the ground.

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[16] Recent data on coal reserves of China are given by the National Geological Survey of China, "Coal and Oil Resources of China," *Third World Power Conference*, Washington, D. C., 1936, sec. IV, Papers Nos. 11 and 12.

What is true of the difference in usefulness of coal between eastern United States and the western part is also to be observed in comparing actively used coal resources in this country with untapped coal resources abroad.

The world estimates of coal resources include information on almost every sizable deposit in industrialized regions where coal has possibilities of extensive utilization. A comparison of coal resources in the United States and abroad, confined to these industrialized regions exclusively, gives our reserves a more favorable position than one based on all regions of occurrence. Outside the United States, two-thirds of the tonnage of coal reserves, according to the 1913 survey, are in Siberia, China, and western Canada. These areas produce little coal at the present time, and they cannot become important producers without revolutionary changes in the location of industry. Although world estimates of coal resources may be enlarged by further discoveries, additions are likely to be made only for remote and sparsely inhabited areas, such as the polar regions, the tropics, and the areas isolated by mountains. The 1913 data on coal reserves do not include estimates for Brazil, Bolivia, Ecuador, Uruguay, Mexico, Costa Rica, Panama, Trinidad, the Dominican Republic, Greenland, and Labrador, even though these are known to have deposits, some of them, as in Brazil and Mexico, of proved commercial value.

Against this tendency toward expansion of the estimates for some regions where coal is now little used, there is a widespread lowering of estimates for regions from which current tonnages are being drawn, as well as for many undeveloped regions. The calculations of reserves in foreign countries have been subject to a bias on the side of overstatement similar to that already described for the United States. Coal reserves have a way of exhibiting their favorable features at the outset, and it is only after careful survey that their limitations are fully appreciated. Even after the first World Power Conference, held in London in 1924, it was learned by geologists interested in the work that the original estimates were far too large and that drastic revisions downward would have to be made.[17] Esti-

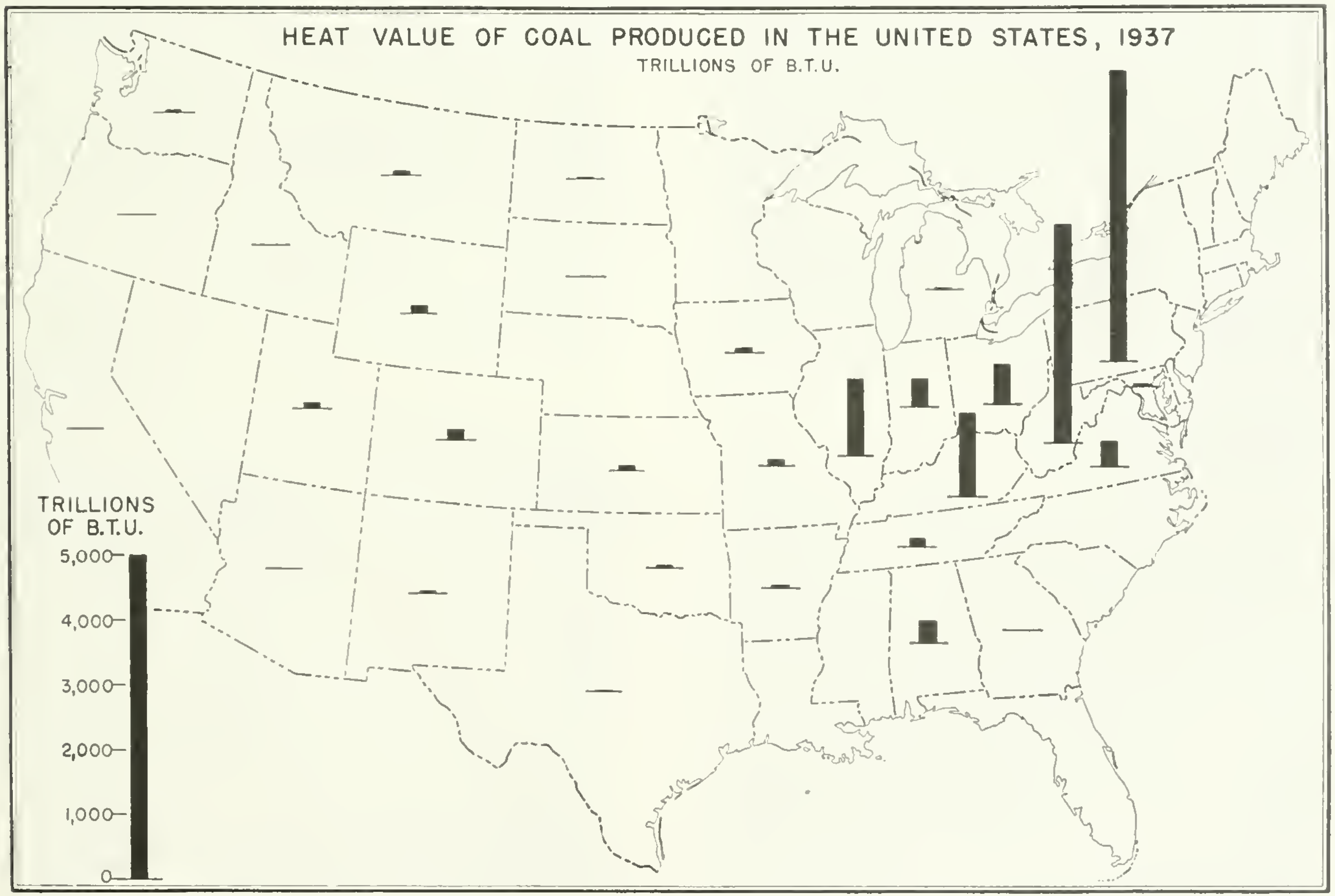
HEAT VALUE OF COAL PRODUCED IN THE UNITED STATES, 1937
TRILLIONS OF B.T.U.
TRILLIONS OF B.T.U.
5,000
4,000
3,000
2,000
1,000
0
Prepared in office of the National Resources Committee

FIGURE 5.

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[17] B. F. Haanel, "Organization of Production, Processing and Distribution of Coal and Coal Products in Canada," *Third World Power Conference*, Washington, D. C., 1936, sec. II, Paper No. 4, p. 2.

mates of reserves for major coal areas represent, for the most part, therefore, liberal representations of the quantity of minable coal; and, of course, the matter of minability may vary from region to region, such questions as rank, purity, pitch of beds, character of overburden, gaseousness of mines, and nearness to ready markets having to be considered in addition to depth and thickness of beds. Notwithstanding these qualifications, the available figures on reserves indicate reasonably well the proportions of reserves in at least the countries making extensive use of their supplies. In this respect the United States and Europe afford an informative comparison. The United States in 1936 produced 34.4 percent of the world's coal energy (lignite, wherever produced, being converted to the equivalent of coal energy units).[18] Four European countries, Great Britain, Germany, Russia, and France, produced an additional 45.6 percent, making a total of 80.0 percent for the 5 countries. Altogether the United States and Europe account for almost 90 percent of the coal output of the world. Ordinarily the quantity of coal produced in Europe runs to about 1½ times the amount produced in the United States. Population is in the ratio of about 4 to 1. The position with regard to coal reserves, however, is very much different. These reserves are almost 5 to 1 in favor of the United States, and, on a per capita basis, they are 19 times as large in the United States as in Europe. This comparison is reassuring from the standpoint of the United States, although it indicates little of significance with respect to what problems of utilization will have to be faced by the coal industry in this country long before the coal is gone, problems now being encountered in many of the European coal areas. It remains true, nevertheless, that the total tonnage of coal reserves in the United States is gigantic.

Coal Reserves and Other Energy Sources

The coal industry in the United States has been on the downgrade in recent years. Greater dependence on other types of fuels is reducing coal consumption and lengthening the life of the coal reserves, but this downward trend does not portend eventual abandonment of coal as a source of energy. The exhaustion of substitute mineral fuels is expected long before coal reserves are exhausted. In 1937, petroleum and natural gas, the chief rivals of coal, supplied 43 percent of the total mineral fuel energy in the United States,[19] but they constituted less than one-fourth of one percent of the Nation's fuel reserve.[20] Whereas coal reserves amount to trillions of tons, proven reserves of petroleum and natural gas can supply energy equivalent to only a few billion tons of coal. Proven reserves of petroleum are estimated at 15½ billion barrels, equal in heat value to about 3½ billion net tons of bituminous coal of average rank; and proven reserves of natural gas are believed to be in the neighborhood of 66 trillion cubic feet, with a heat value roughly equivalent to 3 billion tons of bituminous coal.[21] At first glance, these figures seem large, but they are overshadowed by the figures on coal reserves, which total more than 3,000 billion tons. It must be recognized, of course, that further discoveries of petroleum and gas will add to the estimates of those reserves not now counted. On the other hand, estimates of coal reserves probably will be lowered somewhat, as previously explained, when more accurate measurements become available. At the most these revisions hardly will alter the essential point that oil and gas reserves are only a fraction of the magnitude of the coal reserves (table 1).

Oil shales are a potential source of energy, although no process is known for extracting the oil at costs low enough to compete in present-day domestic markets. Reserves of oil in shales are placed at 92 billion barrels.[22] In terms of the equivalent of bituminous coal, a total of about 21 billion net tons is indicated. This amount is more than three times as large as the coal equivalent of oil and gas, but it remains less than 1 percent as much as the tonnage of coal reserves.

TABLE 1.—*Reserves of mineral fuels and their importance in terms of heat value*

Fuel	Proven reserves	Estimated heat value	
		Trillions of B. t. u.	Percent of grand total
	Tons		
Anthracite	15,415,622,000	395,557	0.6
Bituminous coal	1,407,808,291,000	38,578,947	56.9
Subbituminous coal	818,083,894,000	15,543,594	22.9
Lignite	939,457,443,000	12,588,730	18.6
Total coal	3,180,765,250,000	67,106,828	98.9
	Barrels		
Petroleum	15,500,000,000	97,650	0.1
	Cubic feet		
Natural gas	66,000,000,000,000	74,603	0.1
	Barrels		
Oil in shales	92,000,000,000	579,600	0.9
All fuels	----------------	67,858,681	100.0

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[18] Report of the International Labour Office, *Technical Tripartite Meeting on the Coal-Mining Industry*, Geneva, May 1938, Part 1, Economic Conditions, p. 54.

[19] *Minerals Yearbook, 1938*, p. 704.

[20] Rice, Fieldner, and Tryon, *op. cit.*, p. 5.

[21] For estimates of the reserves of petroleum and gas, see pt. one, sec. 11, ch. 2, and pt. two, sec. 1, chs. 2 and 3, this volume.

[22] Dean E. Winchester, "The Oil Possibilities of the Oil Shales of the United States," *Federal Oil Conservation Board Report II*, January 1928, pp. 13–14, quoted in Rice, Fieldner, and Tryon, *op. cit.*, p. 5.

The United States has some resources of peat which may be regarded as a partial substitute for coal, although the main use for this resource at present is agricultural. The estimates usually given for peat are those of Soper and Osborn, who estimate the reserves at 14 billion net tons on an air-dried basis.[23] It is difficult to determine how much coal this amount of peat could displace when used as a source of energy. Rice, Fieldner, and Tryon estimate for peat the equivalent of less than eight billion net tons of high-rank coal.[24] They call attention to the destruction of agricultural lands and forests that would occur in digging the peat. Coal mining often results in similar destruction, but undoubtedly on a smaller scale.

It is seen that coal, an irreplaceable fuel resource, looms exceedingly large alongside other irreplaceable fuel resources. There are, however, some sources of energy which are, or may be, replenished in the course of time.

According to a study by the United States Bureau of Mines of the energy supply in 1927, water power accounted for 6.3 percent of the total in the United States, wood fuel for 5.5 percent, animals for 2.5 percent, and wind mills for 0.1 percent.[25] Although the various forms of energy are consumed, to a large extent, for noncomparable uses and by widely differing methods with differing efficiencies, these data afford some basis for showing the significance of coal reserves from the standpoint of present-day rates of utilization. In 1927, replaceable sources of energy provided only one-sixth as much energy as that drawn from the Nation's storehouse of mineral fuels. In relation to all sources combined, bituminous coal provided 50.3 percent, anthracite 8.1 percent, oil 21.4 percent (20.1 percent native and 1.3 percent imported), and natural gas 5.8 percent.

With irreplaceable fuels, increased use means a reduced period of service. Coal beds are great concentrations of energy materials; there are practical advantages in utilizing such a source as long as it lasts. But what are the limitations of the forms of energy that may be renewed? These replaceable energy forms have not found a major position in the American energy market. Some of them have had a declining use. Animal power might be increased were a future need to arise. The rate of increase would be limited at the extreme by the rate of reproduction; practically, of course, no supply of energy approaching the amount derived from coal could be developed without severe strain on agricultural resources. Furthermore, animal power is being outmoded by technological progress. The horse cannot replace the motor in an automobile, although they both deliver what we choose to call horsepower. A comparison of the 1927 study with an analogous study for 1923, also by the Bureau of Mines, indicates that animal power is declining as a percentage of total energy.

Another replaceable source of energy is represented by synthetic fuels derived from agricultural products. This source is often considered to constitute a limitless fuel reserve and to offer a means of solving the problem of agricultural surpluses. These synthetic fuels, up to the present time, have not succeeded in penetrating the market for high-grade fuels, not to mention the wide market for low-cost heating and generation of power. Alcohols produced from vegetation, especially rapidly growing plants, may some day become important, but current indications are that they would displace oil and gas more than coal. In fact, the processes of distillation for the production of liquid hydrocarbons may work better when applied to coal than to bulkier agricultural products. It must be recognized that carbon universally found in plant life is the basic element in fuels. Coal contains in concentrated form the carbon accumulated by plants, and its use eliminates the necessity of doing the concentration artificially. Furthermore, one must visualize the appalling drain on land resources and the peril to the Nation's food supply were the attempt made by agriculture to meet the ravenous requirements for power. In years of active business, the Nation's annual tonnage of coal "crop" is about 20 times as large as that of the wheat crop and about 7 times as large as that of the corn crop; besides, coal is, without conversion, a more concentrated and a more convenient source of power.[26] Increase of a major agricultural crop 20-fold, or even 7-fold, is no doubt impossible irrespective of the serious effects of such increase on the soil. Agricultural waste products likewise would be an inadequate source.

Wood is a fuel resource more widely utilized for power under present conditions in the United States than either animals or farm crops, although it is less easily replaced. The data for 1927, cited previously, indicate that, in use for power, wood was more than twice as important as animals. Synthetic fuels, of course, were used in negligible quantities. Wood was about two-thirds as important as anthracite and one-ninth as important as bituminous coal. Before the day of mineral fuels, wood, wind, and water were the sole sources of power, excluding muscular power, but these sources have lost their standing. Wood is probably losing ground in actual quantity.

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[23] E. K. Soper and C. C. Osborn, *The Occurrence and Uses of Peat in the United States*, U. S. Geological Bulletin 728, pp. 92–93. Also *Minerals Yearbook, 1938*, p. 809.

[24] *Ibid.*

[25] *Mineral Resources of the United States, 1927*, Part II, p. 405.

[26] Cf. P. Burke Jacobs, "Motor Fuels from Agricultural Products," pt. two, sec. III, ch. 3, this volume. Also, *Use of Alcohol from Farm Products in Motor Fuel*, S. Doc. No. 57, 73d Cong., 1st sess., May 1, 1933.

Much of the wood fuel produced at present is a byproduct of the lumbering industry and would not be used were a surplus not available. In the Douglas fir region of Washington State, a region west of the Cascade Mountains, sawmill waste equivalent to 3,200,000 tons of coal is burned, but only about three-fourths is consumed to develop energy, the remainder being destroyed in waste burners for want of a market.[27] Despite this surplus, fuel oil is used to supplement "hogged" fuel (wood waste) in specific instances where a considerable portion of the waste is utilized in pulping operations. This readiness to substitute oil for wood waste produced locally in abundance reflects the limited possibilities of wood utilization in competition with mineral fuel. Although coal is considered a bulky commodity, wood is far more cumbersome to handle than coal. It takes about 200 cubic feet of hogged fuel for the heat equivalent of three-fourths of a ton of coal of only 9,500 B. t. u. per pound,[28] or 400 cubic feet to equal 1 ton of high-grade coal (about 14,000 B. t. u. per pound). A cubic foot of solid coal weighs at least 81¼ pounds,[29] and a net ton requires about 25 cubic feet, or only one-sixteenth the space required for wood. Loose coal, of course, occupies more space than solid coal but certainly only a fraction of that required for wood. The greater difficulty of transporting and utilizing wood is clearly suggested, and, in fact, the market is extremely localized in contrast with that for coal.

Should this obstacle of bulkiness be overcome by conversion of wood to a concentrated fuel, there would remain the problem of obtaining an adequate supply. Obviously the waste product of the lumbering industry is insufficient to meet any extensive demand; a wood-fuel industry operating independently and at higher cost would have to be developed. The possibility of any marked expansion, moreover, appears to be beyond consideration because, with the present rapid rates of timber destruction and slow rates of restoration, increased utilization would result in further unbalance. The traditional symbol of individualism, the farm wood lot, is on the decline, and an increasing number of farmers are resorting to coal or oil. Under the most favorable circumstances, reforestation may not meet more than the nonfuel demand for wood.

Wind power at present probably does not supply more than one unit of energy out of a thousand. It is highly important, however, in the great plains region, and has been a major factor in the settlement of that region, particularly in the grazing areas where water had to be pumped for livestock. The amount of unharnessed wind power is almost boundless. Perhaps increased use would be profitable, but the major demand today is for precision power, and wind is far too undependable to provide that type of energy.

Among the replenishable sources of energy, water power from streams has gained prominence. In regions of steep stream gradients and heavy rainfall, it is usually a leading source. The limits of water power availability are known, although points of view vary widely with respect to what may be used profitably.[30] The United States Geological Survey estimates potential water power available 90 percent of the time at 42,753,000 horsepower.[31] This capacity, if fully used, would generate power equal to that obtainable from 204,000,000 net tons of coal [32] on the basis of the average central steam-electric station performance in 1937 (1.42 pounds of coal per kilowatt-hour).[33]

F. G. Tryon, in testimony delivered in the Carter Coal case before the United States Supreme Court, stated that, in his opinion, water power could never supply more than a minor fraction of the energy requirements of the country.[34] If every drop of water falling as rain in the United States could be transformed into power at the existing gradients, the supply of energy would not equal that derived in good years from coal. This estimate was made by the eminent scientist, Charles P. Steinmetz.[35] Similar calculations presented at the Third International Conference on Bituminous Coal afford confirmation of the limitations of water power: the entire run-off of water, if it could be put to work, would yield annually the energy equivalent of 437,000,000 tons of coal.[36] Actual production of anthracite and bituminous coal combined was 609,000,000 tons in 1929 and 494,000,000 tons in 1937. These comparisons, of course, do not indicate the extent to which development of available water power is a feasible undertaking. They do show, however, that power in streams, although replenished, cannot yield more than a fraction of the energy derived from coal. Power actually produced from falling water in 1937 was equivalent in energy value to only 6½ percent of the coal mined that year.[37] Potential water power is about 21 percent developed.[38] At the 1937 rate of utilization of capacity, maximum output of potential water power would have been the equivalent of 31 percent of the coal tonnage used that year. This percentage is probably a reasonably good indication of the limits of water power use, considering the current characteristics of the power load.

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[27] P. Hetherton, *Energy Resources, State of Washington*, Washington State Planning Council, Olympia, revised typewritten copy, October 1938, p. 5.

[28] *Ibid.*, appendix No. 4, p. 2.

[29] See T. A. Hendricks, pt. two, sec. I, ch. 1, this volume. Also, refer to S. B. Flagg, *Weights of Various Coals*, U. S. Bureau of Mines, Technical Paper 184 (1918).

[30] A discussion of potential water power is presented by J. P. Watson, pt. one, sec. III, this volume.

[31] *Potential Water Power in the United States* (mimeographed), August 20, 1936, p. 3. Computed from the gross head with allowance for future storage at feasible reservoir sites and assuming 70-percent efficiency in water utilization.

[32] Cf. Rice, Fieldner, and Tryon, *op. cit.*, p. 2, footnote 2. A coal equivalent of 183,000,000 net tons is estimated using a potential capacity figure of 80,000,000 horsepower and a 48-percent capacity use factor. The higher equivalent, of 204,000,000 net tons, quoted above, assumes 100-percent utilization of a capacity sufficient to use the stream flow available 90 percent of the time.

[33] It should be observed that the figure on central station coal consumption is somewhat low for the purpose of this comparison because (1) it does not include coal consumed in transporting coal to the power plant, (2) it is greatly affected by the high efficiency of mammoth steam plants in the northeast, and (3) performance is based to a considerable extent on the consumption of Appalachian coal not duplicated in quality in most other areas. The figure is a national average, not an average of performance in areas of available water power.

[34] October Term, 1935, No. 636, *Transcript of Record*, vol. 1, p. 288.

[35] *Ibid.*

[36] George A. Orrok, "The Economics of Water Power vs. Steam Power," *Proceedings, Third International Conference on Bituminous Coal* (Carnegie Institute of Technology, Pittsburgh, Pa.), 1931, vol. 1, pp. 254 and 255.

The replenishable sources of energy, falling water, wood, wind, work animals, and synthetic fuels from crops, do not have unlimited possibilities of expansion. Years of scientific investigation thus far have failed to discover means for giving these "substitutes" for coal a major position in the market for energy. Their period of use, however, may be extended indefinitely. The possibility that any one of them will assume a major share of the burden carried by irreplaceable fuel seems remote, although, as a group, they may grow in importance as the cost of producing mineral fuels rises. Demand for power is not indiscriminate; instead it is a selective demand, its character depending on a comparatively delicate adjustment of fuel source to type of use. If these replenishable forms of energy cut into the market for coal, it undoubtedly will be because of improved adaptation to precision uses. Conversion of vegetation to a liquid or gaseous fuel and regulation of stream flow better to meet consumption requirements are the most promising leads. Progress along these lines may outdistance that in the utilization of coal, but such a development appears improbable. The safest assumption is that the most economical energy of the future will be derived from mineral deposits. Shorter life for oil and natural gas than for coal eventually will throw the main burden of the demand for mineral fuel on coal reserves.

Quality of Coal Reserves

There are great differences among coals. Every bed of coal has peculiar characteristics. This fact is fully appreciated in the coal industry, but it is too frequently overlooked by those on the outside. The term "good coal" may have a variety of meanings, in view of the variety of purposes for which the coal is to be used. Coal may rank high or low in fixed carbon content, high or low in volatile matter; it may contain large amounts of moisture or be almost moisture free. These factors are the principal ones determining the rank of the coal. There are other characteristics more or less related to the ones mentioned determining quality or grade. Friability, hardness, ash content, sulphur content, tendency toward caking when burned, fusibility of ash, ease of ignition, smokiness of flame, structure, degree of freedom from clay and other foreign matter, specific gravity, resistance to oxidation when exposed to the atmosphere, and heat value are factors affecting quality. Beds of coal show differences in thickness, depth, width, pitch, laminations and partings in the coal, nature of adjacent strata (the roof and floor of the bed having especially to be considered), number of beds in an area, distance between successive beds, gaseousness of workings, amount of water, ease of drainage, extent of faulting and folding, accessibility of the bed for removal of coal, and location with reference to markets.

Obviously, no simple classification of coals can be satisfactory for every purpose. Certain factors, nevertheless, assume a foremost position in a majority of uses. Coals may be classified as follows:[39]

1. Meta-anthracite.
2. Anthracite.
3. Semianthracite.
4. Low-volatile bituminous.
5. Medium-volatile bituminous.
6. High-volatile A bituminous.
7. High-volatile B bituminous.
8. High-volatile C bituminous.
9. Subbituminous A.
10. Subbituminous B.
11. Subbituminous C.
12. Lignite.
13. Brown coal.[40]

To provide a much more extensive classification of organic materials, the list might be headed by diamonds, which are carbon in purest possible form, and followed by graphite, which is almost pure carbon. At the other extreme, the list might be extended to include peat, wood, and other vegetable matter, and, finally, living plants. The list thus amplified is directly correlated, going from bottom to top, with the evolutionary development of coal, beginning with the capturing of carbon from the atmosphere by the protoplasm of plants and leading to its gradual condensation into valuable deposits. The energy in coal goes back for its origin to the time when the green chlorophyl in plants put sunlight to work gathering the rare carbon atoms from the air. Coal deposits are therefore inimitable warehouses of "solidified sunlight."

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[37] Based on data in *Minerals Yearbook, 1938*, p. 703.

[38] United States Geological Survey, *Total Capacity of Water Wheels at Water-Power Plants in the United States*, January 1, 1937 (mimeographed).

[39] "Standard Specifications for Classifications of Coals by Rank," *A. S. T. M. Standards on Coal and Coke* (American Society for Testing Materials, 1938), pp. 104–111.

[40] Brown coal sometimes is considered to be any coal with a brownish appearance. In this classification the distinction is that lignite is consolidated, whereas brown coal is unconsolidated.

Dr. Robert A. Millikan, who has made outstanding studies of atomic energy, says that all the energy used by man is obtained from the sun, and he ventures the guess that a billion years hence all energy needs for light, warmth, and power will come from the sun; energy derived from the disintegration of radioactive or other atoms has no commercial future.[41] That a relatively direct utilization of sunlight by photoelectric cells, direct capture of heat from the sun, use of temperature differences in water or the substrata, or manufacture of synthetic hydrocarbons by direct application of sunlight or from rapidly growing vegetation ever will be able to compete with coal as long as available reserves remain in the ground is open to doubt. In fact lack of coal resources in the higher stages of development is a handicap in many areas. Reserves of lignite are not now mined extensively because higher rank coal is more economical and desirable. Fuels ranking below lignite may be expected to offer even greater obstacles, although the fact that their utilization requires an entirely different technique introduces considerable uncertainty; one must compare costs of mining mineral fuels with costs of more direct appropriation of the cruder forms of energy.

Actual inventories of coal reserves do not provide a classification as detailed as that shown above. Wide variations in rank sometimes occur in small areas, as in the States of Colorado and Washington, and it is impracticable to attempt to account for all the differences found. The major differences, however, have been recorded. Reserves available as of January 1, 1937, have been classified into anthracite (of all kinds), bituminous coal (including low-volatile and medium-volatile coal), subbituminous coal and lignite.[42] Most of the coal mined at the present time is either anthracite or bituminous coal, but undoubtedly a larger quantity of anthracite would be mined if reserves were more widely distributed and as easily mined as those of bituminous coal. The tonnage of high-rank coal in the ground is decidedly limited. Anthracite constitutes only about one-half of 1 percent of the total tonnage of coal reserves.[43] Bituminous coal constitutes a little more than two-fifths of the total reserves, and the remainder is the much less desirable subbituminous coal and lignite. Furthermore, 29.5 percent of the anthracite had been mined or lost up to January 1, 1937, whereas only 1.9 percent of the bituminous coal was gone. The tonnage of subbituminous coal and lignite mined or lost was almost an imperceptible percentage of the total, being less than one-tenth of 1 percent.[44] In the estimates prepared by M. R. Campbell of reserves at the end of 1928, somewhat further detail on this tendency is given. Campbell gave a separate listing for semibituminous coal (now called low- or medium-volatile bituminous coal), which ranks between semianthracite and high-volatile bituminous coal. The estimates show that semibituminous coal has been going at a more rapid rate than coals of lower rank, although not as rapidly as anthracite. Up to the end of 1928, 2.6 percent of the semibituminous coal had been mined or lost.[45] What is happening is that we are starting at the high ranks of coal and working down. This method leaves for the future a succession of increasingly difficult problems to solve.

In terms of heat value, reserves of higher rank coals make a better showing than in terms of tonnage. An-

TABLE 2.—*Coal reserves of the United States, by States, Jan. 1, 1937 (bituminous coal equivalent in thousands of net tons)*

State	Anthracite	Bituminous	Subbituminous	Lignite	Total
Alabama		66, 627, 383			66, 627, 383
Arizona		9, 973	791, 413		801, 386
Arkansas	206, 438	1, 293, 088		44, 019	1, 543, 545
California		24, 169	10, 941		35, 110
Colorado	84, 732	212, 617, 050	72, 148, 249		284, 850, 031
Georgia		916, 295			916, 295
Idaho		598, 054	69, 294		667, 348
Illinois		197, 794, 658			197, 794, 658
Indiana		51, 973, 927			51, 973, 927
Iowa		28, 692, 767			28, 692, 767
Kansas		29, 653, 642			29, 653, 642
Kentucky		121, 546, 161			121, 546, 161
Maryland		7, 677, 918			7, 677, 918
Michigan		1, 933, 607			1, 933, 607
Missouri		83, 681, 170			83, 681, 170
Montana		2, 609, 060	43, 580, 341	154, 297, 864	200, 487, 265
New Mexico	61	18, 810, 479	1, 291, 598		20, 102, 138
North Carolina		66, 135			66, 135
North Dakota				293, 433, 359	293, 433, 359
Ohio		91, 960, 301			91, 960, 301
Oklahoma		54, 755, 853			54, 755, 853
Oregon		59, 924	344, 040		403, 964
Pennsylvania	13, 524, 449	103, 300, 820			116, 825, 269
South Dakota				498, 700	498, 700
Tennessee		25, 289, 831			25, 289, 831
Texas		7, 984, 076		11, 214, 450	19, 198, 526
Utah		87, 976, 203	3, 572, 680		91, 548, 883
Virginia	453, 281	20, 646, 578			21, 099, 859
Washington	21, 321	11, 250, 150	36, 345, 477	245	47, 617, 193
West Virginia		147, 748, 138			147, 748, 138
Wyoming		30, 310, 881	409, 105, 334		439, 416, 215
Total	14, 290, 282	1,407,808,291	567, 259, 367	459, 488, 637	2, 448, 846, 577

Source: Pt. two, sec. I, ch. 1, this volume.

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[41] *Science*, September 28, 1928, vol. 68, No. 1761, p. 279. See reference in Rice, Fieldner, and Tryon, *op. cit.*, p. 2, footnote 3.

[42] Hendricks, *loc. cit.*

[43] *Ibid.*

[44] *Ibid.*

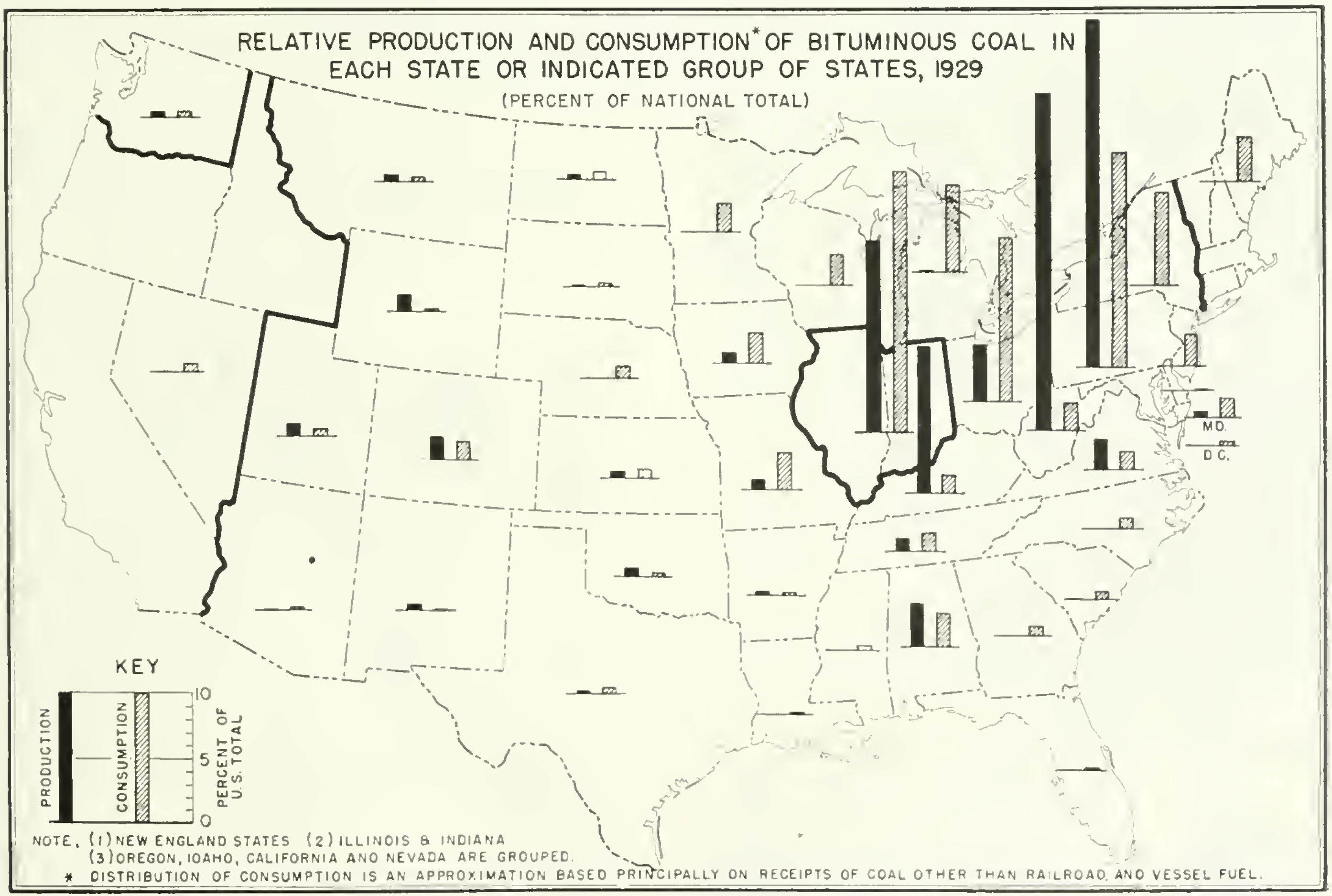
[45] Campbell, *loc. cit.*

thracite reserves are estimated to have an average heat value of 12,700 B. t. u. per pound, bituminous coal reserves 13,700 B. t. u., subbituminous coal reserves 9,500 B. t. u., and lignite reserves only 6,700 B. t. u.[46] Hence, a pound of bituminous coal has, on the average, more than twice as much heat value as a ton of lignite. Bituminous coal and anthracite reserves combined have about four-fifths of the total heat value (table 2). When low-rank coals are mined, a larger tonnage will have to be taken to meet a fixed heat requirement. Rates of exhaustion will then be accelerated, and, if the cost of mining and marketing per ton remains unchanged, the cost per heat unit will increase. Heat from lignite, for example, will cost more than double that now obtained from bituminous coal under the assumption of fixed cost per ton.

The proportion of fixed carbon obtained from various rank coals likewise varies. In general, the percentage of fixed carbon increases with the rank of the raw coal. There is some exception to the rule when adjustment is not made for ash and moisture content of coal. Meta-anthracite, for example, commonly has less fixed carbon than anthracite in the raw state, that is, not on an ash-free, dry basis. Owing to the fact that low-rank coals contain smaller amounts of fixed carbon[47] combined with greater amounts of moisture and volatile matter, depletion of the high-rank coals means depletion of the carbon supply in a proportion larger than that reflected by coal tonnage mined or lost. Industries using carbon from coal may be affected seriously by diminution of the carbon supply, when high-rank coal, such as that suitable for metallurgical coke, becomes less readily available.

Location of Reserves

The geographic distribution of coal consumption shows little relation to the distribution of coal reserves. Fourteen Northeastern States consumed, in 1929, about 71 percent of the total coal used, excluding railroad and vessel fuel.[48] The proportion had increased from 67


RELATIVE PRODUCTION AND CONSUMPTION* OF BITUMINOUS COAL IN EACH STATE OR INDICATED GROUP OF STATES, 1929
(PERCENT OF NATIONAL TOTAL)
MD.
D.C.
KEY
PRODUCTION
CONSUMPTION
10
5
0
PERCENT OF U.S. TOTAL
NOTE. (1) NEW ENGLAND STATES (2) ILLINOIS & INDIANA
(3) OREGON, IDAHO, CALIFORNIA AND NEVADA ARE GROUPED.
* DISTRIBUTION OF CONSUMPTION IS AN APPROXIMATION BASED PRINCIPALLY ON RECEIPTS OF COAL OTHER THAN RAILROAD AND VESSEL FUEL.

Prepared in office of the National Resources Committee

FIGURE 6.

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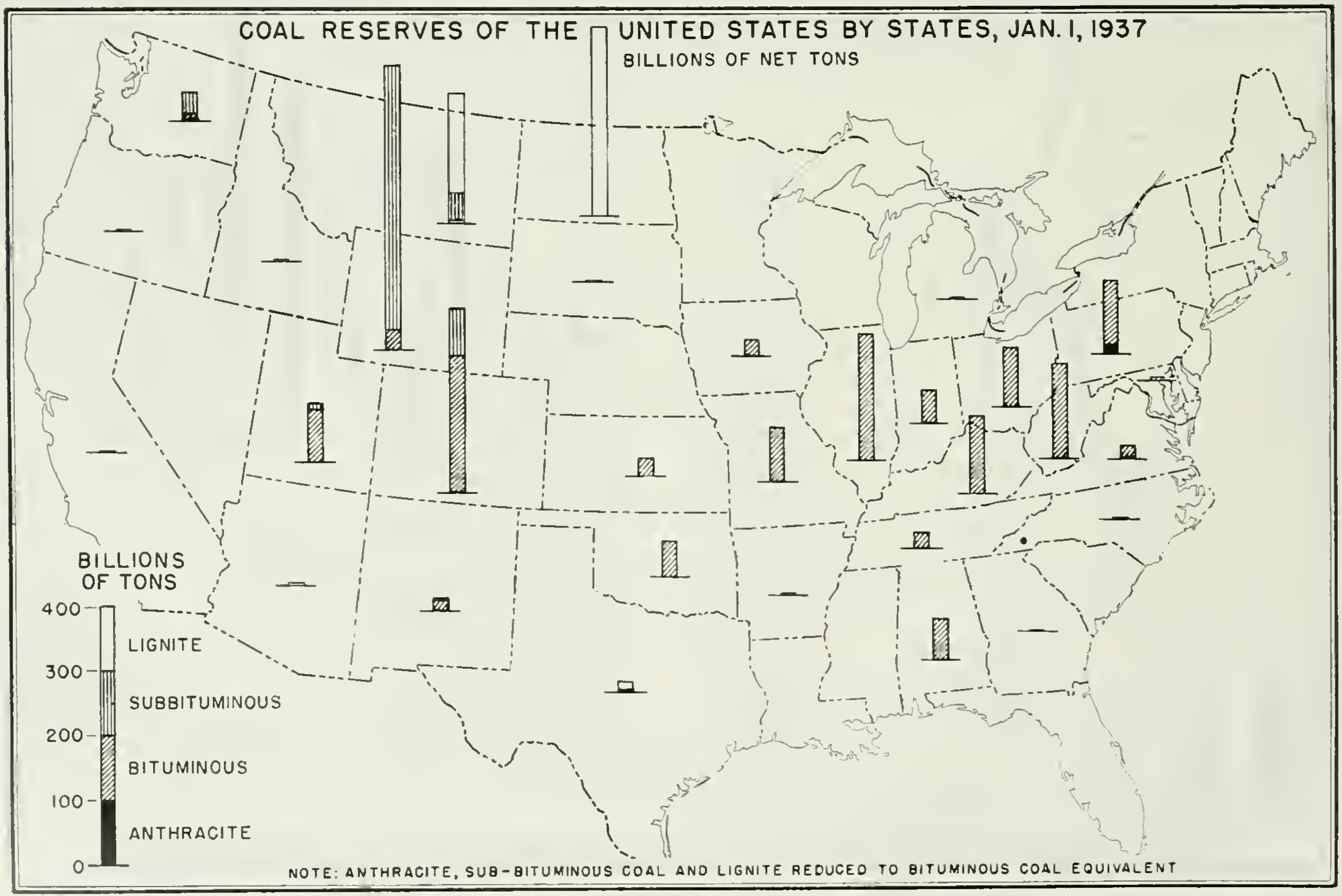
[46] Hendricks, *loc. cit.*

[47] On an ash-free basis.

[48] Wilbert G. Fritz and Theodore A. Veenstra, *Regional Shifts in the Bituminous Coal Industry*, University of Pittsburgh, Bureau of Business Research Monographs, No. 4 (1935), p. 109.

percent in 1917. These States, on the other hand, have only 15 percent of the coal reserves of the Nation. It is true in a general way that the coal reserves are widely distributed. Thirty-one States contain significant amounts of coal. The coal-reserve map, nevertheless, is spotty when coal of specified ranks is considered (table 2). Eastern Pennsylvania has 95 percent of the anthracite; Wyoming has 72 percent of the subbituminous coal; North Dakota has 64 percent, and Montana, 34 percent of the lignite.[49] The bulk of the high-quality coking coal occurs in the Appalachian Province. The so-called smokeless coals of southern West Virginia are not widely duplicated. Six Eastern States, Pennsylvania, West Virginia, Illinois, Kentucky, Ohio, and Indiana, produced 85 percent of the Nation's coal in 1937, but these States have only 23 percent of the reserves (in terms of tonnage). At the other extreme, seven Western States, Colorado, Missouri, Montana, North Dakota, Utah, Washington, and Wyoming, have 68 percent of the tonnage reserve but produced in 1937 only 6 percent of the coal. Utilization of coal reserves is thus badly distributed geographically. When the reserve supply begins to disappear, it will do so at the most vulnerable points. The pattern of industrial location, having a direct dependence on low-cost coal, may have to be reshaped as soon as the pinch of exhaustion, or even partial depletion, is felt. Extensive transportation of coal makes the delivered price prohibitive for the bulk of uses. Industry, therefore, cannot reach out to distant points and draw in what it needs as it does with rare metals. A good example of the heavy expense of transporting coal a long distance to major eastern consuming centers is presented by Rice, Fieldner, and Tryon.[50] With freight rates assumed to be at the low level of one-half cent per ton-mile, Trinidad, Colo., coal (suitable for coking) would cost $7.85 per ton in Chicago, $9.20 in Detroit, and $10.10 in Pittsburgh at 1934 mine prices. In contrast, much better coking coal from the Appalachian fields was obtainable at a cost of only $4.48 per ton in Chicago, $3.90 in Detroit, and $2.51 in Pittsburgh. Coals from the Far West would be still more expensive and lower in quality than those from Trinidad, Colo. One may well contemplate the in-


COAL RESERVES OF THE UNITED STATES BY STATES, JAN. 1, 1937
BILLIONS OF NET TONS

NOTE: ANTHRACITE, SUB-BITUMINOUS COAL AND LIGNITE REDUCED TO BITUMINOUS COAL EQUIVALENT

Prepared in office of the National Resources Committee

FIGURE 7.

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[49] Hendricks, *loc. cit.*

[50] *Op. cit.*, p. 8.

crease in the cost of steel produced with the costly western coals or the migration of industry which that increase in cost would necessitate. A shift of industry, of course, would leave whole areas stranded, and would result in enormous loss of investment (cf. figs. 6 and 7).

It is not necessary, however, to assume a shift from coal fields east of the Mississippi River to those westward to indicate the adverse effect of coal exhaustion. On the average, coal travels but short distances. In 1932 the average length of haul by rail was only 188 miles, according to studies made by the Section of Transportation, Federal Coordinator of Transportation. The average freight per ton-mile was 65 one-hundredths of 1 cent. Haulage of a ton 3 miles added, on the average, about 2 cents per ton to the cost of the coal.[51] In 1936 the average mine price of bituminous coal was $1.77 per ton, and the average railroad freight payment was $2.25 per ton. (Some coal, of course, is shipped by water or by truck or wagon and some is consumed at the mine.) More than half the average delivered cost of coal shipped by rail as revenue freight, therefore, consisted of the freight charge. This heavy expenditure for transportation is incurred despite a tendency to work fields most favorably located with regard to consuming markets. In many areas the addition of only a few miles to the haul places a producer at a disadvantage. The effect of exhaustion in fields near the consuming markets is an increase of the cost of transportation and, unless mining costs are reduced, an increase also of the delivered price of the coal.

Mining of the Best Beds

Coal-mining companies seeking to make profits naturally will avail themselves of the most favorable opportunities for mining. The struggle for existence forces the companies to focus their operations on the beds most amenable to mining, and the remaining beds are, in the main, treated as submarginal.

Mining today may be classified into four types based on the method for gaining access to the beds. These methods are (1) strip, (2) drift, (3) slope, and (4) shaft mining. A limited proportion of the coal is so near the surface that the overburden of rock and dirt may be removed with power shovels, leaving the coal exposed for loading into cars. This strip mining may be carried on with heavy machinery and usually costs less than mining at considerable depths underground. The Colstrip operation in the Rosebud field of Montana is stripping a bed of subbituminous coal 24 feet thick under a cover of only 20 to 50 feet.[52] In 1935 this pit produced 1,142,000 tons of coal.[53] The 61 men employed during the year produced an average of 68.9 tons per man per day, against an average for all strip mines in bituminous coal fields of 11.2 tons. This is probably the cheapest energy, measured in terms of human labor, produced at any coal mine in North America.[54] Cubic yards of overburden per ton of coal reaches 18.5 in one mine, and coal lying at depths up to 60 feet from the surface (in isolated cases 85 feet for short distances) has been stripped.[55]

Among underground mines, those near the surface predominate. The favorite underground method today is to tunnel into the side of a hill at the outcrop of the coal, following the contour of the coal bed as the mining progresses. By this method—drift mining—no tunnels need be burrowed into the rock for the purpose of reaching the coal; the entries, or gangways, may be developed with the active mining of the coal. In Pennsylvania in 1930, 72.5 percent of the bituminous coal mines were drift mines; 14.5 percent were slope mines, that is, mines having tunnels sloping into the coal bed at grades low enough to permit mine cars to be pulled over tracks; 11.3 percent were shaft mines; and 1.7 percent were combination shaft and slope, or drift and slope mines.[56] Other data on type of opening are presented in table 3.

According to a 1926 study, the average depth of shaft mines in the United States was only 262 feet, but more than 64 percent of the coal was removed in drift or slope mines.[57] An increase in the depth of mining not only magnifies problems of ingress and egress but also adds to the difficulty of ventilation, support of overburden, and drainage of water. A large percentage of mines now operated are above stream-bed level, so that water may be pumped out easily. Moreover, with beds above the drainage level, less water is likely to get into the mine. The anthracite region gives an excellent illustration of the problem of handling water in relatively deep workings. Thirty-three tons of

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[51] Exact mileage rates, of course, are not charged. There are marked differences in freight rates among hauls of about the same distance and among producing fields. Rates are usually higher per ton-mile for short hauls than for long hauls. The rate, for example, from the Belleville, Illinois, district to St. Louis, a distance of 15 miles, averaged 70 mills per ton-mile, whereas that from the Pocahontas district in southeastern West Virginia to Chicago, a distance of 582 miles, averaged only 5.31 mills per ton-mile. These rates do not take into account emergency adjustments. W. H. Young, "Truck Movement of Coal from Mines," *Proceedings, Third Pennsylvania Mineral Industries Conference* (Coal Section), Pennsylvania State College Bulletin 15, November 1933, p. 6.

[52] O. E. Kiessling, F. G. Tryon, and L. Mann, *The Economics of Strip Coal Mining*, U. S. Bureau of Mines, Economic Paper 11 (1931), p. 20.

[53] *Minerals Yearbook, 1937*, p. 829.

[54] Kiessling, Tryon, and Mann, *op. cit.*, p. 21.

[55] Toenges and Anderson, *op. cit.*, pp. 80–81.

[56] Computed from data in Commonwealth of Pennsylvania, Department of Mines, *Report 1929–30*, pt. II, "Bituminous," pp. 100 695.

[57] Study of F. G. Tryon and Margaret H. Schoenfeld, "Comparison of Physical Conditions in British and American Coal Mines," *Coal and Coal Trade Journal*, September 1 and 8, October 7, and November 4, 1926.

TABLE 3.—*Thickness of beds and percentage distribution of mines by type of opening, bituminous coal mines in specified States* [1]

State	Year	Number of beds	Annual production [2] (net tons)	Average thickness of beds [3] (inches)		Percentage distribution of mines by type of opening			
				Simple	Weighted	Shaft	Slope	Drift	Strip
Alabama:									
Warrior Field	1917	235	17,246,279	45.2	55.3	3.83	29.36	63.40	3.41
Other [4]	1917	48	3,167,532	55.9	61.7	------	89.58	10.42	-----
Total Alabama	1917	283	20,413,811	47.0	56.3	3.18	39.58	54.42	2.82
Warrior Field	1937	146	10,456,178	40.3	55.4	8.77	49.12	36.84	5.27
Other [4]	1937	44	1,987,867	48.9	69.6	5.88	94.12	------	-----
Total Alabama [5]	1937	190	12,444,045	42.3	57.6	8.11	59.46	28.38	4.05
Colorado	1916	216	10,519,175	80.3	84.8	22.71	41.06	36.23	-----
	1936	317	6,791,003	72.3	86.4	15.24	78.81	5.95	-----
Indiana	1915	164	14,723,413	60.3	64.4	86.59	7.32	5.49	.60
	1936	73	8,562,890	59.7	66.9	95.89	4.11	------	(6)
Kentucky:									
Eastern	1926	530	47,296,167	48.2	53.7	.38	1.31	98.31	-----
Western	1926	180	16,307,936	59.2	61.9	44.45	28.89	23.33	3.33
Total Kentucky	1926	710	63,604,103	51.0	55.8	11.50	8.27	79.38	.85
Eastern	[7] 1936	225	39,006,147	45.9	50.8	------	4.00	96.00	-----
Western	1936	69	7,861,608	58.1	58.4	44.07	33.90	22.03	-----
Total Kentucky	1936	284	46,867,755	48.5	52.1	9.16	10.21	80.63	-----
Ohio	1927	471	[8] 279,123	68.3	61.0	14.78	19.27	58.67	7.28
	1937	121	[8] 149,330	58.0	60.9	19.01	19.83	55.37	5.79
Pennsylvania	1917	1,786	170,960,467	56.4	65.6	10.16	12.80	76.98	.06
	1937	1,126	109,647,937	52.8	64.8	11.42	12.58	75.47	.53

[1] Compiled by D. C. Ashmead, National Research Project, Works Progress Administration. With the exception of Ohio, all data were taken from the published State mine reports. In the case of Ohio, production figures by mines were not available, and daily capacity figures, as given in the *Keystone Coal Buyers Manual*, were used.

[2] The total production figures here used may vary somewhat from the reported totals, due to the fact that it was not always possible to determine the tonnages belonging to certain beds, and vice versa, and in some cases the thickness of beds being omitted, the tonnage was also omitted.

[3] Computation of averages was as follows:

$$\text{Simple average thickness} = \frac{\Sigma(\text{bed thickness})}{\text{No. of beds}};$$

$$\text{weighted average} = \frac{\Sigma\,(\text{bed thickness} \times \text{production})}{\Sigma\,(\text{production})}.$$

[4] Blount Mountain, Coosa and Cahaba Basins.

[5] Of the 190 mines listed in 1937, only 74 reported type of opening, and the percentages have been computed on that basis. The remaining mines were largely wagon mines, and the type of opening was, in all probability, mostly drift.

[6] No strip mines were included in the 1936 report. Only one was listed in 1915.

[7] Railroad mines only; wagon and truck mines not included.

[8] Daily capacity. Since production figures by mines were not available, daily capacity was used as the weighting factor.

[9] Data on production by mines for 1937 matched with data on thickness of beds for 1936, since the two sets of data were not readily available for the same year.

water are pumped for each ton of anthracite produced.[58] The expense of pumping water is by itself a considerable item in deep mining. The amount of water pumped at a group of 73 identical anthracite collieries increased from 19.5 tons per ton of coal in 1927, to 21.8 in 1931, and to 29.3 in 1935.

The average thickness of beds worked underground was, according to the 1926 study, about 63 inches.[59] Coal of such thickness usually can be mined without vertical cramping of operations. It is rather generally agreed that 5–7 feet is the best thickness for mining. Coal much thicker frequently presents a difficult problem of pillar support for the roof, and the coal may have to be worked in benches; thinner beds often do not provide adequate headroom, and they necessitate mining a larger acreage for a given tonnage output. Other factors, of course, such as strength of the coal, character of the roof, and cover, introduce many exceptions.

The Wilkes-Barre district in the anthracite region is illustrative of the necessity of mining thinner beds and at greater depths as resources become depleted (fig. 8). The average thickness of the beds worked in that district decreased from 8.76 feet in 1872 to 5.55 feet in 1935.[60] Depth of workings below mine-mouth levels increased from 170 feet to 505 feet during the same period. The figures for recent years do not show the unfavorable side of depletion, owing to rapid declines in production which temporarily permit concentration on the better beds.

Depth and thickness are not the only physical factors of occurrence determining the value of the reserves of a given quality of coal. In some bituminous-coal areas the coal is badly faulted. Part of the Pennsylvania anthracite beds also are deeply folded. Beds may stand at various degrees of pitch—some of them on end. Although portions of these steeply pitched beds may be mined at low cost, the average cost for the beds is high. Most of the bituminous coal beds now being worked are approximately horizontal, the average pitch being not more than a few degrees.[61] Finally, there are no definitive figures on the question, but it is true that coal with numerous or thick partings of clay or other foreign matter is avoided as much as possible.[62] It is certainly a fact that coal with extremely high ash content (partly related to the question of partings) is not mined and will not be mined until demand is more pressing or better techniques for reducing ash are perfected.

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[58] "Output Per Man in the Preparation and Underground Mining of Anthracite," National Research Project, Works Progress Administration; study being made by D. C. Ashmead and W. F. Whiting, unpublished at the time of this writing. See also, D. C. Ashmead, "Water Pumped from the Mines of the Anthracite Region of Northeastern Pennsylvania," *Transactions, American Geophysical Union, Eighteenth Annual Meeting, 1937*, pp. 498–504.

[59] Tryon and Schoenfeld, *loc. cit.*

[60] Ashmead and Whiting, *loc. cit.*

[61] Tryon and Schoenfeld, *loc. cit.*

[62] The amount of refuse in coal beds is, nevertheless, considerable. The average thickness of Pennsylvania anthracite beds worked in October 1936 was 10.09 feet, but refuse was 1.49 feet thick, leaving a net thickness for the coal beds of 8.60 feet. Ashmead and Whiting, *loc cit.*

Life Expectancy of Reserves

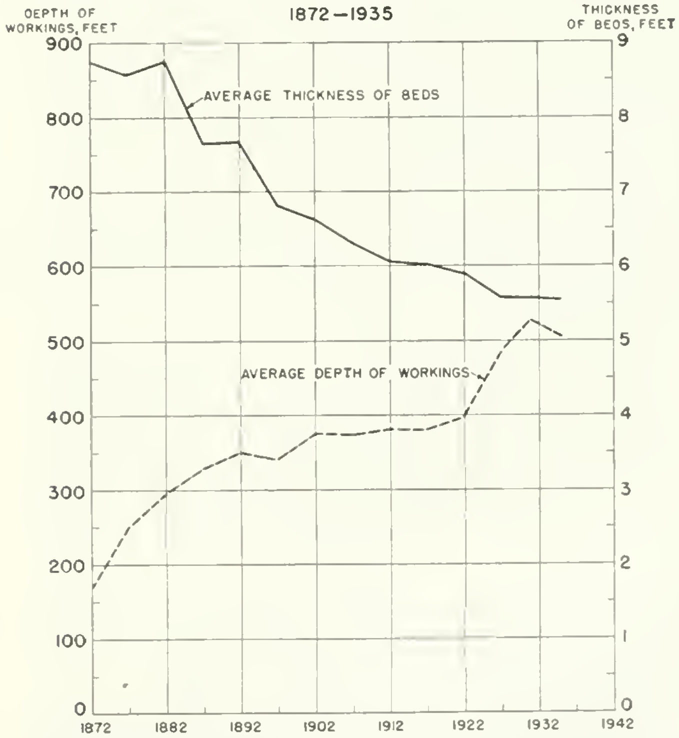
One cannot determine accurately how long the coal reserves of the Nation will last. They will not come to an end at a fixed time. Instead, they will be exhausted piece by piece. Technically, resources of coal will never fully disappear, because there will always be beds just beyond the limit of profitable mining. Because there are all gradations of beds down to those only a fraction of a foot thick, and because mining cannot, except under unusual circumstances, be pursued in such thin beds, an arbitrary limit for minability must be set in computing probable life. The estimates, therefore, are extremely rough clues to the period of usefulness of the reserves.

Estimates of the life of coal reserves may be helpful in conveying a general impression of what may be expected for the future. They should not be interpreted too literally. In a world of rapid change in fuel utilization, the trend of development cannot be accurately forecast. The following analysis of life expectancy of the coal fields is offered to show probabilities rather than to designate any single period as the indicated life span.

There are 3,200 billion tons of coal in the ground in the United States, coal varying widely in heat value and composition and occurring in a variety of formations, which might conceivably be mined with known techniques. The rate of mining and loss depends not only on the methods of conservation and use but also on the trend of total energy demand and the percentage of the demand met by alternative sources of energy. If the 1929 output of coal be set against the total reserves, assuming no change in output to the end and no loss, the reserves have a calculated life of about 5,000 years. One would be brave indeed to accept those assumptions and that period as a basis for future plans. But what are the factors tending to shorten the life of the reserves? First, the probability of early exhaustion of petroleum and natural gas has to be faced. When the reserves of these fuels run low, a heavier burden no doubt will fall on coal.[63] Even a cessation of the rapid growth of petroleum and gas output will tend to force an upward trend in coal consumption in the event of a continuation of rising total fuel demand. Second, when lower rank coals than those now mined are resorted to, a larger tonnage will be needed for a given heat value. Third, demand for a better type of fuel than that represented in crude coal probably will result in the processing of the coal, with resultant loss of heat. This change is likely to occur principally when low-rank coals are used and, in fact, has already been started in connection with the lignite of North Dakota. If liquid hydrocarbons are produced eventually to replace petroleum, coal output will have to increase not only to provide the necessary energy, but also to allow for the thermal inefficiency of the processes. Fourth, the long-run prospects point to an increase in foreign demand.[64] There are, of course, the disadvantages of having to bring in coal from distant mines and of having to mine more difficult beds; these disadvantages are, in the calculations, not reckoned as insurmountable barriers. Rice, Fieldner, and Tryon, in their excellent paper on "Conservation of Coal Resources,"[65] point out that, if all the known reserves of oil, gas, and peat be added to those of coal, and allowance be made for the inferior heat value of low-rank coals and the necessity of replacing oil and gas, the reserves of mineral fuels are sufficient at the 1929 levels of use for 1,730 to 2,250 years, the range reflecting range of assumptions regarding losses in

AVERAGE DEPTH OF WORKINGS* AND AVERAGE THICKNESS OF BEDS IN MINE WORKINGS WILKES-BARRE DISTRICT OF THE ANTHRACITE REGION, PENNSYLVANIA

1872–1935



* MEASURED FROM THE MINE MOUTH TO THE BOTTOM OF THE SHAFT OR SLOPE
TUNNELS AND DRIFTS ARE CONSIDERED TO HAVE ZERO DEPTH

FIGURE 8.

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[63] The assumption is made that energy sources now in the minority will not assume a major role. The reasons for believing this to be true have already been indicated.

[64] Rice, Fieldner, and Tryon, *op. cit.*, p. 6.

[65] *Ibid.*

mining. But if the annual increment of demand for energy observed in the 1920's continues, the reserves will last only 365 to 425 years, the range depending again on range of assumed losses in mining.[66]

In the United States, growth of industry has come to be a normal expectation. The usual concept of economic progress assumes continued expansion of production. It should be observed, however, that a growth of coal mining as much as 1 percent per year could not be maintained until the coal reserves are exhausted. In the final years, the Nation's annual coal production would be at least 8 times as large as world coal production was in 1929. Undoubtedly the handicap of increasingly meager reserves would force a decline of production long before the last tonnages are taken. No calculations of probable life can show adequately the effect of the qualitative decline accompanying depletion of the better reserves. To the extent that the finest deposits are mined first, the coal industry will encounter added problems in mining the remaining coal.

Local Depletion of Coal Deposits

The best coal beds are being mined at a rapid rate, and many are nearly exhausted. The famous Big Vein coal in Georges Creek, Maryland, is almost exhausted.[67] Exhaustion of the virgin portions of this bed accounted for a sharp decrease in output per man from the nineties to the time of the World War.[68] A large number of examples of depletion are cited by George H. Ashley: "The Block coals of Indiana, which were in their day considered a very fine coal, are practically exhausted. The Sharon bed of Ohio, which in its day was considered a very fine coal, is, I think, practically exhausted. The low-sulphur coal of Illinois, while in a thick bed, has a limited life. An examination of the Pocahontas region of Virginia and West Virginia will show a limited life. By that I mean that it has a life measured not in hundreds of years but in scores of years."[69] The Moshannon bed in the Clearfield, Pennsylvania, district is almost gone.[70] The serious unemployment problem in Clearfield County is well known. The Blossburg bed, which is advantageously located at the northeastern fringe of the Pennsylvania bituminous-coal area, is little more than a matter of history.[71] High-quality coals in the high-volatile beds of Kentucky and West Virginia are limited.[72] The most available coal has been taken from around Coalgate, Oklahoma; many of the producing areas in the McAlester, Oklahoma, district have been almost exhausted.[73] In the Osage field of Kansas, mining companies are now working a bed only 21 inches thick.[74] The Big Muddy Creek district of Illinois has all been worked out.[75]

Reserves of thick coal are not generally a large percentage of the total. Probably the total quantity of Pennsylvania bituminous coal in beds more than 5 feet thick is not in excess of 10 billion tons.[76] A similar study for Ohio indicates that 70 percent of the original reserve was in beds less than 4 feet thick.[77] Ashley made a study of the Punxsutawney quadrangle in central Pennsylvania [78] and found that 45 percent of the coal was in beds less than 2 feet thick, 20 percent in beds 2 to 3 feet thick, and 91 percent altogether in beds less than 4 feet thick. Coal more than 5 feet thick constituted only 2 percent of the total. About all the 5-foot coal has been mined, and only a small fraction of the 4-foot coal remains. Beds only 3 to 4 feet thick are thinner than that required for the lowest cost mining. In thin beds a larger acreage must be worked for a given output; operations become more scattered; more transportation is needed; and the lack of height is a handicap to both the miners and the machines. These factors increase the costs of mining.

Depletion is also becoming evident in some comparatively large areas. The anthracite deposits of Pennsylvania are more than 29 percent depleted. The high-quality smokeless coals of southern West Virginia in beds 3 feet or more thick will last only about 85 years at the 1929 rate of mining.[79] The life of the great Pittsburgh bed in Pennsylvania is limited to 100 years at the 1929 rate of production, and the Connellsville coking coal in the Pittsburgh bed, which contributed heavily to the development of the American iron and steel industry, probably will be sufficient for only 20 to 30 years.[80]

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[66] *Ibid.*, p. 6.

[67] "Report of the Planning Committee for Mineral Policy," National Resources Board, *Report, December 1, 1934*, p. 397.

[68] Rice, Fieldner, and Tryon, *op. cit.*, p. 12.

[69] Testimony in the *Carter Coal* case, *op. cit.*, p. 531.

[70] James D. Sisler, *Bituminous Coal Fields of Pennsylvania*, Pennsylvania Geological Survey, Bulletin M–6, pt. II, 1932, p. 182.

[71] John F. Reese and James D. Sisler, *Bituminous Coal Fields of Pennsylvania*, Pennsylvania Geological Survey, Bulletin M–6, pt. III, 1928, pp. 136–37.

[72] Ashley, testimony in the *Carter Coal* case, *op. cit.*, p. 531.

[73] Frederick Lynne Ryan, *The Rehabilitation of Oklahoma Coal Mining Communities*, University of Oklahoma Press, Norman, 1935, p. 72.

[74] Rice, Fieldner, and Tryon, *op. cit.*, p. 11.

[75] A. Bement, *Illinois Coal*, Bulletin No. 56, Illinois Geological Survey, 1929, pp. 21, 38, 39.

[76] George H. Ashley, *Bituminous Coal Fields of Pennsylvania*, Pennsylvania Geological Survey, Bulletin M–6, pt. I, 1928, p. 162.

[77] J. A. Bownocker, *The Coal Fields of Ohio*, U. S. Geological Survey, Professional Paper 100B, 1929, p. 38.

[78] George H. Ashley, *Topographic and Geologic Atlas of Pennsylvania, No. 65*, Pennsylvania Geological Survey, 1926, p. 127.

[79] Howard N. Eavenson, "The Low-Volatile Coal Field of Southern West Virginia," *American Institute of Mining and Metallurgical Engineers, Transactions*, 1932, vol. 101, p. 95.

[80] Ashley, testimony in the *Carter Coal* case, *op. cit.*, p. 533.

Most coal-bearing areas have several beds of coal appearing at various levels. When the uppermost bed has been completely mined, operations may be shifted to a lower bed. The deeper coal actually may be thicker than the shallower coal, but greater depth of mining will add to the costs of production. In some areas mining takes place at two or more levels. Data on a single bed may be somewhat misleading as a portrayal of the incidence of exhaustion. In Pennsylvania, the Upper Freeport bed, below the Pittsburgh bed, contains more coal than the Pittsburgh bed,[81] although the coal is not so heavily concentrated in a few counties. The Pennsylvania Geological Survey lists 14 beds of bituminous coal of commercial value in Pennsylvania. Three of the beds, however, have three-fifths and five of them have three-fourths of the total coal.[82] In many regions, nevertheless, as in the Pennsylvania anthracite regions, total resources have reached a high percentage of depletion. In Allegheny County, Pennsylvania, in which Pittsburgh provides a large urban market for coal, more than three-fourths as much coal has been mined or lost as remains recoverable.[83] The county is approaching the halfway mark in tonnage, but it is a certainty that the last half of the reserves will be much more difficult to mine than was the first half. The condition in this area foreshadows the problems to be encountered generally when coal reserves reach a mature stage of utilization.

Conclusion on Coal Reserves

Current evidence points to greater reliance on coal than on any other source of energy. From a realistic view of the Nation's coal reserves, it must be recognized that complete exhaustion of the reserves probably will not occur for hundreds, possibly thousands, of years. Except probably for a brief interlude, coal may continue in the future, as it has in the past, to be more important than all other sources of energy combined. This prospective dependence of our civilization on coal should lead us to consider what problems will arise concerning our coal reserves long before complete exhaustion is threatened. To what extent can the Nation afford to gamble with the future of the coal reserves under a policy of irresponsible exploitation? The answer appears to be one of budgetary management. The Nation—all groups considered—can ill afford to waste its coal resources if the penalty in the form of higher costs of production, accompanied by lower standards of fuel consumption, outweighs temporary gains accruing from skimming the best and allowing the remainder to be added to the already huge quantity of coal that never will be mined even under pressing needs for fuel. A national accounting shows that reasonable conservation measures will yield dividends under the conditions of increasing costs in the coal industry. The extent of conservation advisable depends on (1) the present state of utilization, (2) the cost of conservation, and (3) the increase in future costs of mining attributable to current waste. Ultimate exhaustion is only a minor consideration. More important is the extent to which waste leads to dependence on poorer and less accessible deposits; attention is directed chiefly to this immediate problem.

CHAPTER 3.—INDUSTRIAL PROBLEMS OF THE COAL INDUSTRY

Character of the Uses of Coal

Since the World War marked changes have been made in the technology of coal utilization. The rise of the byproduct coke industry is indicative of the changes that have been taking place. The extensive introduction of automatic stokers has also resulted in improved efficiency.

In general, two forms of energy are derived from coal. First, a comparatively simple heat energy, and, second, a more complicated mechanical or motivating energy commonly called power. Mechanical energy is one step farther removed in the process of conversion than is heat energy, and efficiency, accordingly, is lower than that for conversion to heat (fig. 9). In addition to being the major energy material, coal is also a storehouse of many chemicals fitted to a wide range of nonenergy uses.

It appears that the technology of coal utilization is still in its infancy and that there are possibilities of further improvements that will overshadow those of the past. Many of the methods of use of coal remain inefficient. This is especially true of small-scale uses such as residential use. The preference of consumers for automatic heating portends development in that direction. Automatic control in utilization requires either conversion of the raw coal to a condition in which the heat value of the coal may be more readily utilized, or equipment that will handle the coal with more facility during the process of combustion.

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[81] George H. Ashley, *Bituminous Coal Fields of Pennsylvania*, Pennsylvania Geological Survey, Bulletin M–6, pt. 1, 1928, p. 158.

[82] *Ibid.*, pp. 158–59.

[83] Fritz and Veenstra, *op. cit.*, pp. 16–18 and 177. Estimates pertain to 1926 and allowance must be made for coal mined or lost since that year.

The original cost of coal per ton is being weighed more heavily against satisfactory performance in utilization. Because of this change in attitude, technical considerations must be taken into account in the sale of coal. A conversion of coal to a different form, such as coke or semicoke, of course, is a recognition of this fact. But improvements in equipment and in methods of handling fuel also are being made, and these necessitate better selection of grades, types, and sizes of coal. To make better selection possible, coal producers should understand the fuel problems of the customer and be able to give accurate information concerning the properties of coal.[1] Items of chief importance to the cussumer are as follows:[2]

1. *Moisture content.*—As the moisture in coal increases, the heat value decreases. Costs of steam production and of coal handling are both affected by moisture content. Coal having a large quantity of free moisture may present difficulties in handling during freezing weather.

2. *Ash content.*—High ash content means reduced heat value. more ash handling and, accordingly, higher cost from that source. The thermal efficiency of utilization need not be materially affected by ash content up to 12 percent, but this depends on the fusibility of the ash and on the equipment. Coals with very low ash content may be troublesome because of lack of protection for the grates.

TYPICAL PROPORTIONS OF CONSUMPTION OR LOSS IN THE UTILIZATION OF COAL RESOURCES

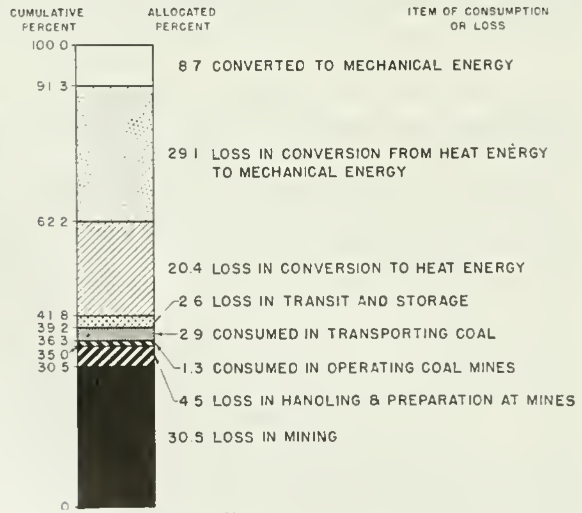

FIGURE 9.

3. *Heat value.*—This item fixes the cost of the potential heat energy.

4. *Sulphur content.*—Sulphur in coal may be troublesome for certain uses, such as metallurgical use, but otherwise the item has been overemphasized in connection with handling high sulphur coal in the furnace and in storage.

5. *Ash-fusion temperature.*—This item indicates the tendency of coal to clinker. A low ash-fusion temperature may cause trouble in certain types of equipment, and, therefore, may be objectionable.

6. *Size.*—This item is important, especially for noncaking coals, as it fixes the resistance to air flow.

7. *Structure.*—Coal structure or friability is of interest to stoker users because of its effect on the proportion of fine coal produced. Hardness affects wear on parts and capacity of pulverizers.

8. *Burning characteristics.*—The burning and caking characteristics of coal are difficult to measure except by actual burning tests. Thus far very few objective standards have been established.

A principal reason for believing that coal utilization will become more complicated is that the composition of coal is complex. Coal consists of numerous combinations of hydrogen and carbon.[3] The original material from which coal was derived contained lignin, resins, waxes. fats, cellulose, starches, sugars, gums, mucilage, pectin, turpentine, camphor, and other substances which were subjected to bacterial attack.[4] Starches and sugars and cellulose were destroyed, and parts of them were dissipated into the air as carbon dioxide. The remaining material of value as fuel consists chiefly of carbon, hydrogen, and oxygen.[5]

Patent characteristics of coal include color, banding, grain, luster, structure, fracture, cleavage, hardness, and weight.[6] Coals are not, as a rule, uniform in texture. Most of them have alternating bands of bright and dull coal, and they usually have no distinctive structure; that is, they are massive in character. Luster, or shininess, however, differs considerably among the various ranks of coal. Anthracite resembles black glass, whereas cannel coal has a satiny luster. Hardness of coal may range from that found in lignite, which can be crushed in the hand, to the graphitic coals of Rhode Island, which are extremely difficult to break. Fracture is an important property of all coals, such as conchoidal fracture of anthracites and cannel coals and irregular fracture of splint coals.

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[1] A rather full but concise consideration of the properties of coal may be found in *Five Hundred Tests of Various Coals in House Heating Boilers*, U. S. Bureau of Mines Bull. 276.

[2] E. J. Kerr, "Utilization Investigations," *Coal Mining Mechanization Yearbook, 1934*, pp. 201–212.

[3] R. Thiessen, "What is Coal," *Record of Meetings of Fuel Engineers of Appalachian Coals, Inc.*, 1937, vol. 4, pp. 211–272.

[4] James B. Sisler, *The Romance of Coal*, West Virginia Geological Survey Commission, Mimeograph Series 1, Bull. 3, April 1, 1931, p. 1.

[5] *Ibid.*, p. 8.

[6] *Ibid.*, p. 7.

Other characteristics, not visible to the naked eye, may be seen under a microscope. The microscopic appearance of coal is not black or sooty.[7] A cross section of even a dirty lump of coal shows colors in brown and gold. The cellular structure of the plants from which the coal originated becomes visible. Scattered throughout the coal are thousands of spores of club moss and ferns and pollen of many kinds of flowers. Bright bands consist of wood which has been changed to coal. These bands show a woody structure, but the wood is not from trees of present-day varieties but rather from tree ferns and giant plants. Layers of charcoal occur in association with the bright and dull bands.

Thousands of commercial products are obtained from coal. The complexity of utilization increases as the temperature of treatment of coal decreases, because high temperature tends to break down the complex substances in coal to simpler forms. But even the high-temperature process used in byproduct ovens yields a large range of products. Among the byproducts are motor fuels, road oils, tars, resinous products, dyes, explosives, flavoring extracts, drugs, disinfectants, insecticides, briquette binders, wood preservatives, paint materials, varnishes, rubber, fertilizers, soaps, roofing materials, and materials for electrical apparatus. Coal also contains inorganic minerals; that is, those that do not contain carbon. Studies of samples of coal have shown the existence of pyrite, kaolin, muscovite, calcite, quartz, limonite, magnetite, gypsum, hematite, tourmaline, siderite, zircon, garnet, and other minerals not used as fuel.[8]

Production Tendencies

In the period before the World War the coal industry was one of the Nation's most rapidly growing industries.[9] Problems that might have been grave in the event of a stationary or declining output often disappeared in the face of mounting consumption requirements. Production commonly doubled every 8 or 9 years (fig. 10). This rapid growth existed in both the bituminous coal and the anthracite industries, although the anthracite industry showed some tendency toward retardation of growth earlier than the bituminous coal industry. From 1840 to 1850 bituminous coal production showed an increase of 161 percent. A peak rate of gain was shown in the decade from 1860 to 1870, when the increase was 168 percent. This rate of gain was maintained almost unabated until 1890, after which there was more tendency toward retardation, although the gain was 91 percent from 1890 to 1900 and 97 percent from 1900 to 1910. It is noteworthy that from 1910 to 1920 the gain was only 36 percent and that in the decade from 1920 to 1930 the trend was downward. Production of anthracite has been decreasing more rapidly since the World War than production of bituminous coal. In fact the output of Pennsylvania anthracite decreased from almost 100 million tons in 1917, the peak year, to approximately 50 million tons during the past several years. The comparatively low levels of business activity in recent years, of course, may account, in part, for the slump in production, but it should be remembered that anthracite is largely a residential fuel and, therefore, is not greatly affected by business cycles. Anthracite production in 1937 was less than that in 1936, even though average business levels were higher in 1937.

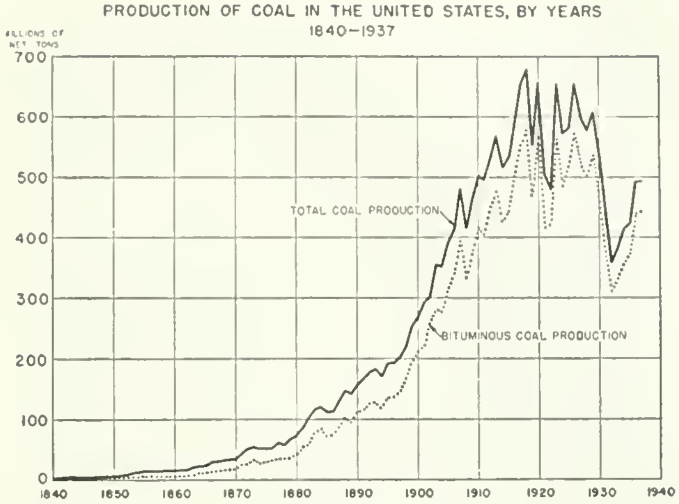

FIGURE 10.

Growth of total coal production, including both anthracite and bituminous coal, was 6.5 percent per year from 1870 to 1902, and from 1903 to 1916 it was only 4.5 percent per year, whereas for the period from 1917 to 1929 it declined 0.2 percent per year, despite the fact that business generally was active in the latter part of the period.[10] Total coal production entered a period of marked retardation in the early 1900's; nevertheless, new high levels continued to be reached until

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[7] *Ibid.*, pp. 6–7.

[8] A. W. Gauger, "Coal and Its Mineral Matter with Reference to Carbonization," reprinted from *Blast Furnace and Steel Plant*, April, May, and June 1936, p. 4.

[9] T. A. Veenstra and W. G. Fritz, "Major Economic Tendencies in the Bituminous Coal Industry," *Quarterly Journal of Economics*, November 1936.

[10] Based on trend lines calculated by Louis J. Paradiso on the staff of the National Resources Committee.

1918. From that date until 1923 the trend was approximately horizontal, but since 1923 the trend has been clearly downward. Production during the 1929 peak was lower than that of preceding peak years, and at no time during the 1930's was the 1929 peak approached. Table 4 shows the production in 1900 and in selected years since.

The first recorded production of bituminous coal in the United States was in 1750, when 500 tons were mined.[11] This production occurred in Virginia. There was no production in any other State until 1759, when the Pittsburgh bed began to be worked. Anthracite mining began on a commercial scale in 1776. Production in that year was only 100 tons against 8,850 tons for the bituminous coal industry. Before 1775 the Nation imported more coal than it produced. In subsequent years, however, imports have lost ground relatively. Since 1873 exports of coal usually have been larger than imports. Growth of the anthracite industry was slow until 1821. From 1776 to 1820 output increased only from 100 tons to 700 tons. Beginning in 1821, rapid increases were registered annually so that by 1841 production exceeded 1 million tons. At the opening of the Civil War, it was about 10 million tons. Growth of the bituminous coal industry was more regular. Almost from the start the industry showed a comparatively steady growth. From 1821 to about the time of the close of the Civil War the anthracite industry grew more rapidly than the bituminous coal industry. Indeed, anthracite production was larger than bituminous coal production during the period from 1841 to 1864 and also in several subsequent years. In connection with the development of the use of coke in the steel industry during the 1870's, the bituminous coal industry began to show an accelerated growth and soon left the anthracite industry far behind. By 1900 the bituminous coal industry reached an output of 212 million tons, whereas anthracite production was only 57 million tons. The bituminous coal industry showed an all-time peak of production in 1918, when output was 579 million tons. The peak in the anthracite industry came in 1917 and amounted to almost 100 million tons. The largest annual post-war production of bituminous coal was 569 million tons, reached in 1920 but closely approached in 1923; in the anthracite industry, the post-war peak was 93 million tons, reached in 1923. In 1937, a comparatively good year in business generally, bituminous coal production was 442 million tons and anthracite 52 million tons (both figures preliminary). The figures on anthracite production do not include bootleg (illegal) production, an important factor in recent years. In 1936–37 the bootleg industry produced anthracite at an estimated rate of 2,400,000 tons a year.[12] This was equal to nearly 5 percent of the total legally mined anthracite in Pennsylvania, but it is lower than many of the guesses published previously. In the peak year, 1935, bootleg output scarcely reached 2,900,000 tons.[13]

Despite the retardation of growth in the coal industry, the United States remains the largest producer and consumer of coal. During the past 35 years, more coal has been produced and consumed in the United States than in the entire previous history of the country.

TABLE 4.—*Coal production by States, for selected years*

[Thousands of net tons]

State	1900	1913	1918	1929	1937
					Prelim.
Alabama	8,394	17.678	19,185	17,944	12,400
Arkansas	1,448	2,234	2,227	1,695	3,200
Oklahoma	1.922	4,166	4.813	3,774	
Colorado	5,244	9,232	12,408	9,921	7,153
Georgia and North Carolina	334	256	68	97	15
Illinois	25,768	61.619	89,291	60,658	51,240
Indiana	6,484	17,166	30,679	18,344	17,270
Iowa	5,203	7,526	8,192	4,241	3,690
Kansas	4,468	7,202	7,562	2,976	7,044
Missouri	3,540	4,318	5,668	4,030	
Kentucky	5,329	19,617	31,613	60,462	47,053
Maryland	4,025	4,780	4,497	2.649	1,570
Michigan	849	1,232	1,465	805	561
Montana	1,662	3,241	4,533	3,408	3,075
New Mexico	1,299	3,709	4,023	2,623	1,795
North Dakota	130	495	720	1,862	2,105
South Dakota	----------	11	8	13	
Ohio	18.988	36,200	45,813	23,689	24,500
Pennsylvania	79,842	173,781	178,551	143,516	110,160
Tennessee	3,510	6,860	6,831	5.406	5,292
Texas	968	2,429	2,261	1,101	879
Utah	1,147	3,255	5,137	5,161	3,750
Virginia	2,394	8,828	10,290	12,748	13,558
Washington	2,474	3,878	4,082	2,521	2,010
West Virginia	22,647	71,254	89,936	138,519	118,050
Wyoming	4,015	7,393	9,439	6,705	5,930
Other States	231	73	18	20	25
Total bituminous	212,315	478.433	579,310	534,888	442,325
Pennsylvania anthracite	57,368	91,525	98,826	73,828	51,856
Grand total	269,683	569,958	678,136	608,716	494,181

Source: *Mineral Resources of the United States* and *Minerals Yearbook*. Alaskan production is excluded.

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[11] Howard N. Eavenson, *The Pittsburgh Coal Bed*, American Institute of Mining and Metallurgical Engineers, New York, 1938. table 1 in back-cover pocket.

[12] *Report of the Anthracite Coal Industry Commission*, Commonwealth of Pennsylvania, Harrisburg, July 30, 1938, p. 43.

[13] *Ibid.*, p. 44.

There are three major reasons for retardation of growth of the coal industry. Slower growth of population and of industry generally, of course, has had an adverse effect. Second, there has been the factor of fuel economy, particularly in the electric power, railroad, and steel industries. Undoubtedly more important than the other two reasons have been the inroads into coal markets made by competing fuels.

In the long run, exhaustion of oil and gas reserves very likely will throw more of the burden of providing energy on coal reserves. A major shift of that burden, however, is improbable for many years. Even if domestic supplies of petroleum become badly depleted, petroleum will, no doubt, be imported from foreign sources. The prospects are that the long-term trend of the coal industry will continue to be downward for some time. Further inroads by the oil and gas industries appear to be imminent, and further introduction of technological improvements in coal consumption also seems likely to have a depressing effect on production. Despite marked economies already introduced by railroads, a new type of locomotive has been built recently which, it is said, will reduce fuel consumption to one-half.[14] Although this locomotive is an oil steam-turbine electric engine, a similar type burning coal by automatic stokers could be built. The lack of adaptability of temperature of the fuel bed, of course, would reduce the efficiency somewhat.

Coal probably will not displace all competing fuels. In the event of relative exhaustion of petroleum and natural gas, fuels may be produced from oil shales or from agricultural products, and greater use would be made of the Nation's water power resources. Stimulation of demand for coal by reduction of prices appears largely out of the question. Price reduction would necessitate decreases in wage rates, and such decreases are improbable with the present strong unionization of the industry. Since the industry is already operating at a deficit of income available for supplies, equipment, power, and other expenses, as well as for depreciation and depletion, the share cannot be reduced without impairing the future of the industry. Furthermore, the demand for coal is inelastic. It is doubtful that a considerable decrease in price would result in sizable increases in total consumption of coal, at least not sufficient increase to yield a larger total income.[15]

At present, mining is concentrated largely on the thick and accessible beds, which are being rapidly depleted. The result will be an early dependence on leaner and more inaccessible beds, in which coal is available only at increasing costs. Currently about 12 percent of the output consists of anthracite, which constitutes only one-half of 1 percent of the total reserve. Likewise, about 17 percent of the output is semibituminous coal, which constitutes slightly less than 2 percent of the reserve. Among the bituminous coal ranks, production centers on the best coal. It would appear that the downward trend in coal production would be decidedly helpful in preserving the resources. Practically, however, decreased demand for coal induces more concentration on the thicker and more accessible beds.[16] The disrupting effect of a downward trend also brings about intermittent and wasteful production.

Bituminous coal, being used to a large extent by industry, tends to fluctuate with the variations in general business activity. Mines delivering coal to certain types of industries are, of course, directly subject to the fluctuations in those industries. Captive mines in Fayette County, Pa., for example, which produce coal for the iron and steel industry, show the very wide fluctuations characteristic of that industry. Short-term swings of coal output are erratic, being subject to the effects of such factors as strikes, threats of strikes, variations in amount of coal in storage, weather conditions, and faulty anticipation of demand (fig. 11). On a yearly basis, however, fluctuations of bituminous coal production show a close correlation with those of business activity (fig. 12). Anthracite production, unlike bituminous coal production, shows small cyclical swings, but the very short fluctuations are unusually erratic. Since anthracite is used mostly by residential consumers and the small commercial trade, the problem exists of anticipating consumer demand during the heating season. The uncertainties of weather conditions also cause short-terms irregularities.

In addition to these cyclical and erratic variations, there are seasonal swings in production of coal. Seasonal variations in the demand for anthracite, of course, are extremely wide. Some attempt to smooth out the seasonal fluctuation is made by offering special price discounts during the summer and early fall

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[14] Cf. *Railway Age*, December 24, 1938, pp. 916–19, and *New York Times*, January 1, 1939, sec. 10, p. 1.

[15] The question of fluctuations in production of coal and the relationship of such fluctuations to other factors is being investigated, under the direction of Dr. Gardiner C. Means, by the Industrial Section of the National Resources Committee.

[16] This tendency is evident in data collected by D. C. Ashmead and W. F. Whiting for the anthracite industry in a national research project being conducted by the Works Progress Administration (report not yet published).

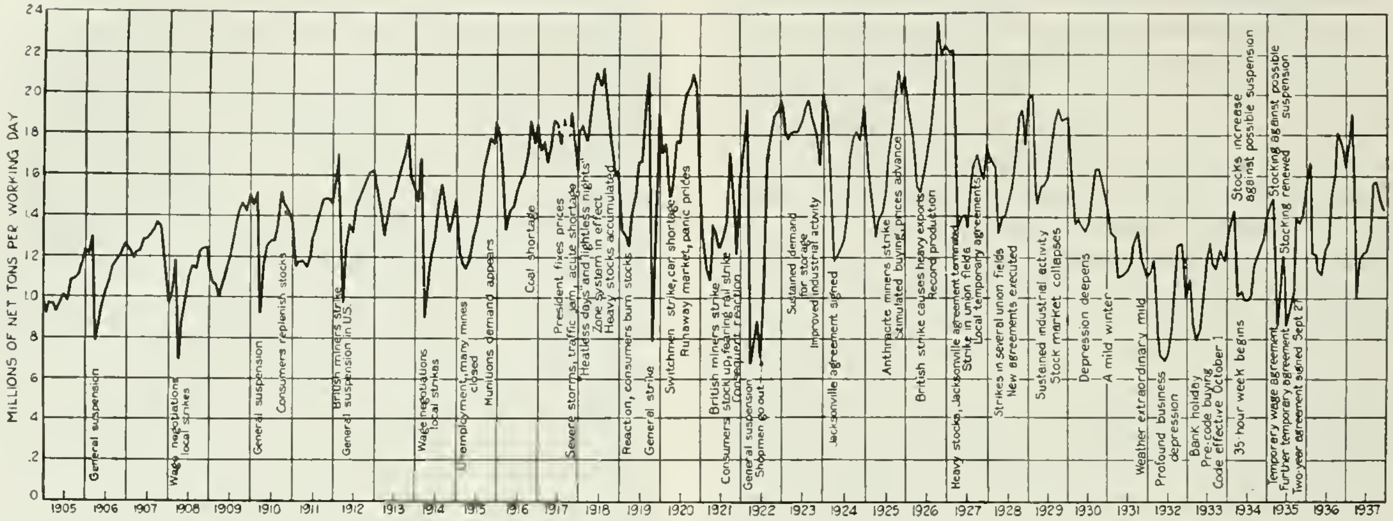

FIGURE 11.—Average Production of Bituminous Coal per Working Day, by Months, 1905–37. (Reproduced from *Minerals Yearbook, 1938*, p. 690.)

months. Although bituminous coal production fluctuates less seasonally than anthracite production, the amplitude of the swing is comparatively large. Production of bituminous coal, typically, is only about 67 percent as large during the lowest month of the year as it is during the highest month.[17] Consuming industries which operate continuously during the year, of course, provide a steady demand. Wherever bituminous coal is consumed largely by residential users, the seasonal fluctuations are considerable. In the Middle West and western sections of the country, where residential consumption is relatively more important than in the heavy manufacturing sections of the Northeast, shipments of bituminous coal from the mines reach a high peak during the fall and winter months and a low level during the spring and summer months (fig. 13).[18] Much of the bituminous coal produced in the Appalachian fields is shipped on the Great Lakes. During the winter months lake traffic is suspended; consequently all shipments have to take place during the open season. This factor concentrates delivery of coal during the spring, summer, and fall months of the year. Fortunately, these months are, to some extent, months of slack demand from other sources. Accordingly, the lake trade helps to stabilize the seasonal demand. Bad weather conditions sometimes deter operation in strip, or surface, mines. Occasionally heavy rains flood underground mines and force suspension of operation.

Figures representing averages or totals of coal production conceal, in part, the irregularities of operation existing at individual mines. The problem of irregularity of operation, therefore, cannot be adequately analyzed by reference to national data or even data pertaining to States or other large areas. When data for various mines are combined, a spurious stability is the result. The problem of instability, therefore, needs to be analyzed by individual mines or at least for small producing regions. Individual operators have the problem of meeting not only a demand for coal but also a demand for certain qualities and sizes of coal. Trading of coal to meet this demand would help to stabilize the output of producers, but grading of coal is insufficiently developed and the market too disorganized to encourage extensive trading.

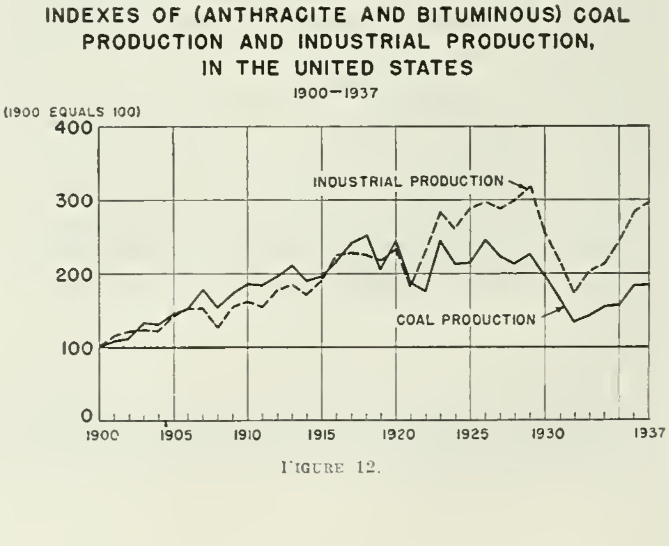

FIGURE 12.

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[17] W. G. Fritz and T. A. Veenstra, "Some Major Problems of the Bituminous Coal Industry," *Pittsburgh Business Review*, December 28, 1936, p. 19. See also *Mineral Resources of the United States, 1927*, pt. II, pp. 406–407.

[18] *Minerals Yearbook, 1938*, p. 691.

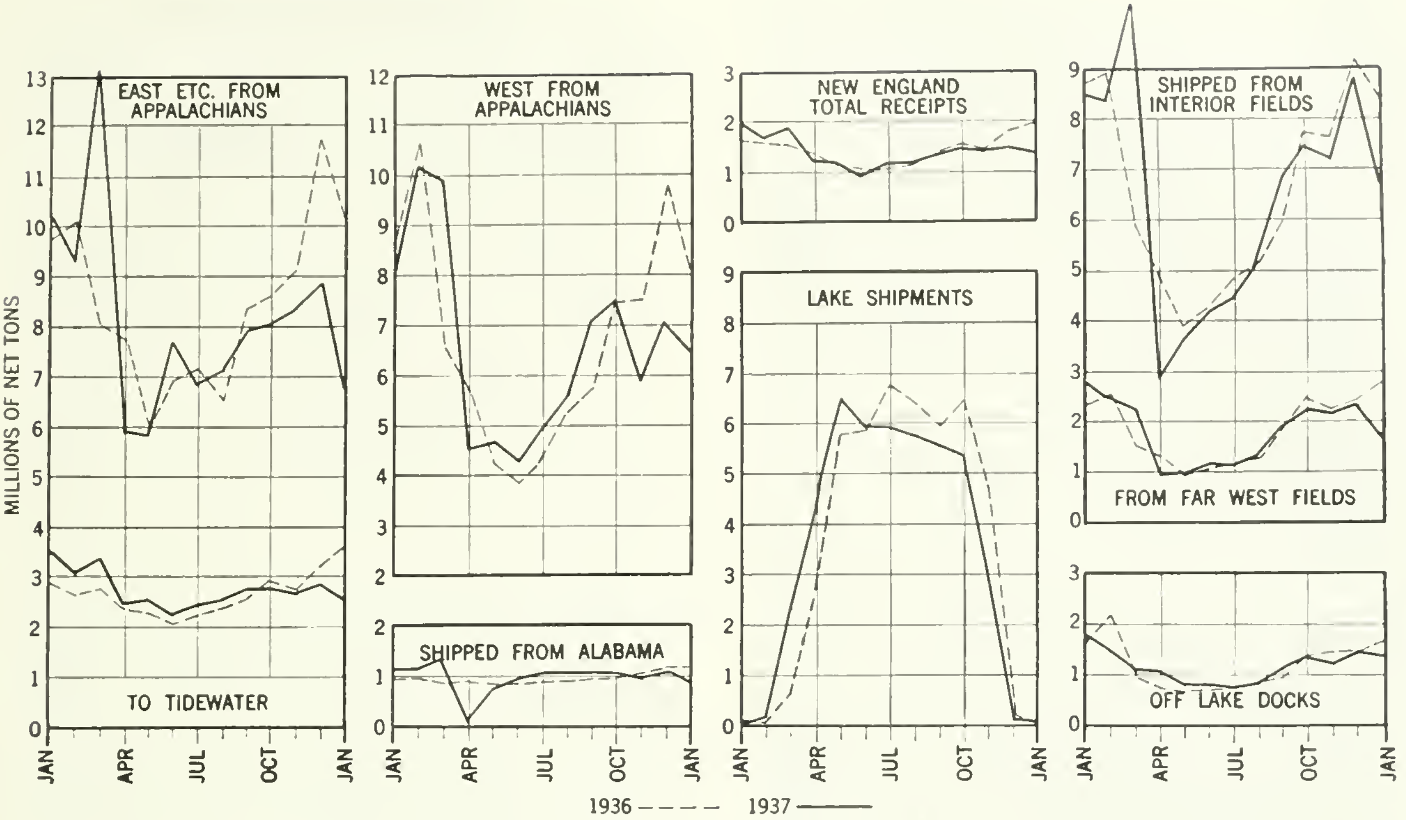

FIGURE 13.—Movement of Bituminous Coal into Major Channels of Distribution, by Months, 1936–37. (Reproduced from *Minerals Yearbook, 1938*, p. 691.)

Capacity Changes

The coal industry normally operates with a large excess of capacity. It must be ready on short notice to meet heavy demands. Coal ordinarily is consumed soon after it is produced, and, accordingly, mines must be ready to adjust their output to changes in the demand by consumers. There are various ways of calculating capacity for production of coal. When the industry operated 6 days of the week, the operating schedule might include 308 days during the year. Mines, however, cannot avoid some loss of time resulting from mechanical breakdowns, accidents, roof falls, failure of power, and other circumstances. F. G. Tryon has made a study of the operating performance of 2,000 mines over a period of 5 years to determine how much time a typical mine loses during the year.[19] About 9 days were lost because of failures of an accidental nature. He calculated an idleness of 34 days resulting from more or less unavoidable seasonal lulls in demand. If allowance be made for these two factors, the average number of working days throughout the year is only 265 against a total number of available days of 308. Under current wage agreements the coal industry operates only 5 days per week. Holidays falling within the 5-day schedule, however, frequently are not taken. The schedule for the industry, therefore, permits about 261 days during the year. From this number, of course, some deduction must be made for seasonal losses of time and for failures of accidental character. Perhaps a deduction of at least 35 days should be made for these factors.

It is the practice, nevertheless, to calculate the maximum capacity of the industry irrespective of unavoidable losses of time, that is, capacity is calculated to represent how much coal could have been produced if the mines had operated 308 days under the old schedule or 261 days under the current schedule. Separate allowance is necessary, therefore, for these possible losses of time.

Overcapacity in the coal industry developed largely during and after the World War (figs. 14 and 15).

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[19] Testimony in the *Carter Coal* case, Supreme Court of the United States, October Term, 1935, No. 636, *Transcript of Record*, vol. 1, pp. 293–94.

Unusually high prices and heavy demand during the war years and also post-war labor disturbances contributed to the creation of excess capacity. Wartime conditions encouraged investment in coal mines, and lack of unionization in newly developed areas provided a further impetus when unions became powerful agencies in the older fields. Maintenance of only small freight-rate differentials between long hauls and short hauls enabled remote fields to compete.

There are numerous other factors conducive to the creation of excess of capacity. The low cost of opening mines affords a temptation for new concerns to enter production of coal. Owing to the existence of large amounts of good coal near the surface, it is relatively easy and inexpensive for new competition to develop. Coal near the mine mouth also is relatively the cheapest to recover, excluding development costs. A second factor is the difficulty of closing mines. If a mine is closed, some of the overhead cost must continue or the mine becomes worthless. Abandonment may lead also to loss of investment. Third, the existence of a large number of small mines leads to uncoordinated methods of marketing and irregularity of output. Fourth, seasonal and other fluctuations in demand require the existence of considerable capacity above the average monthly requirements. Fifth, in the early stages of development of a mine, operations may be concentrated on the more accessible portions of the bed and costs may be held to an unusually low level. As the workings get farther from the tipple, costs tend to rise, but investments already made in the mine lead to continued operation. Sixth, some companies have purchased coal reserves far in excess of their needs for many years to come. Property taxes on the holdings create a pressure to obtain income by working some of the excess reserves. Seventh, increasing mechanization of mines has increased the output per man per day. This increase has tended to add to the capacity of mines already in existence. Eighth, a fear of railway-car shortage, uncertainty of demand to be made on stocks of coal stored, and fear of strikes has led to the development of excess capacity.

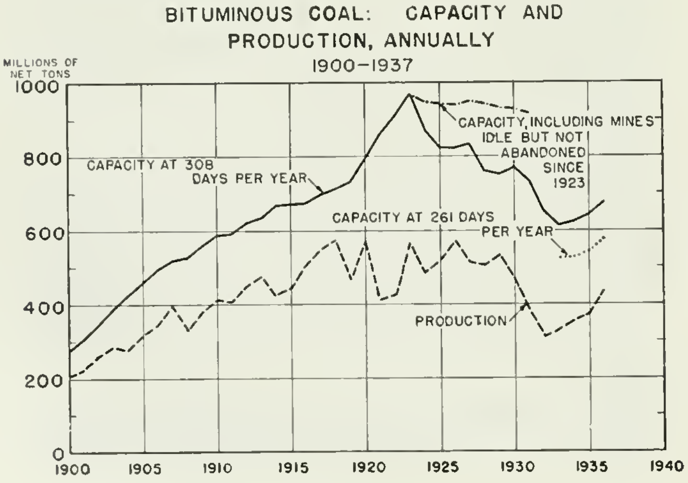

FIGURE 14.

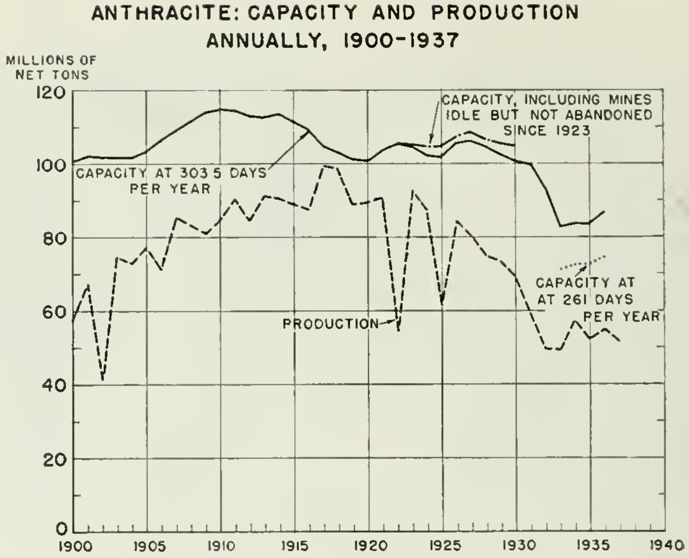

FIGURE 15.

Although the peak of coal production was reached in 1918, capacity continued to grow until 1923. The result in the bituminous coal industry was that the percentage of capacity operations fell from 81 in 1918 to 58 in 1923, even though the latter year was one of large output. Since 1923, capacity has been declining, although not so rapidly as the decline in production. Reduction of working time in bituminous coal mines in 1933 brought about a drastic reduction in capacity calculated on the basis of the regular shifts. Owing to this decline in capacity, it is not impossible that a shortage of capacity may develop if business shows a sharp recovery. A shortage, of course, may be relieved by extension of the number of hours of work per man per week. The data on rated capacity do not tell the whole story because idle mines are not always permanently lost to the industry. Some mines return to production as soon as prices improve. Recent studies of suspensions have indicated that there are numerous mines idle but not abandoned.[20] In addition, there is widespread unemployment of miners who could be put to work producing coal in the event of shortage. These miners might be employed on extra shifts, using principally machinery already installed in the mines.

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[20] Cf. N. G. Alford, "Analysis of Bituminous Coal Mines Suspended from 1923 to 1932, Inclusive," *Transactions, American Institute of Mining and Metallurgical Engineers*, vol. 108, 1934, pp. 476–488. Data for 1910–21 were presented in *Report of the U. S. Coal Commission*, 1925, pt. I, p. 231.

In general, the problem of overcapacity continues to exist in the bituminous coal industry, although there has been some improvement because of abandonment and exhaustion. Shorter hours also have temporarily reduced overcapacity. On the other hand, forces continue to exist which tend to aggravate the problem of overcapacity. First among these forces are the declining long-term trend of coal consumption, the incentive toward further mechanization, and the pressure of carrying charges, such as taxes, on unused coal reserves. Other factors tending toward maintenance of large overcapacity are the seasonal and cyclical peaks in the demand for coal, which encourage operators to keep an excess of capacity; the inelasticity of demand, which prevents consumption from expanding to absorb capacity when wages decrease; and wage differentials favoring mines that in other respects are high-cost mines.

Obviously overdevelopment is accompanied by costs which must be borne either by those in the industry or by consumers. Overdevelopment is correlated with a short work-year both for capital invested in mines and for mine workers. Both have come to expect, and to demand, a full year's return for not more than two-thirds of a year's work. The industry has suffered heavy losses in the past, but, insofar as the expectations and demands will be met in the future, the consumer will be called on to pay the costs of overextension.

Investment, Income, and Business Organization

Nearly all the anthracite production of the country is concentrated in the northeastern section of Pennsylvania. In contrast with this concentration, production in the bituminous coal industry is scattered throughout 31 States. During the period 1934–36, 13 major companies produced 69.4 percent of the total anthracite output of Pennsylvania.[21] Most of the production by these 13 companies was by 10 railroad companies, although three independent companies were also important producers. Of the production by the 13 companies, 55 percent was from lands owned in fee; 14 percent was from lands mined on a royalty basis; about 15 percent was produced by other companies on lands owned by the 13 companies; and the remaining 16 percent was produced by other companies on lands owned in fee or leased from estates, individuals, or companies other than the 13 mentioned.[22]

Production in the bituminous coal industry is much more diffuse, although the statistics on output by size of mine indicate also an appreciable degree of concentration. In 1936, for example, 660 bituminous coal mines, or less than one-tenth of the total number, with an output for the year of 200,000 tons or more each, produced almost 70 percent of the total bituminous coal mined that year.[23] The total number of bituminous coal mines producing 1,000 tons or more per year for which the Bureau of Mines was able to gather information for 1936 was 6,875.[24] The figure indicates a considerable increase over the number found in previous canvasses, which included 6,258 mines in 1934 and 6,315 in 1935. In part, the increase reflects the opening of new mines, especially in connection with the development of hard roads and cheap motor transportation; but it also reflects to some extent more complete coverage. The National Bituminous Coal Commission has been attempting to compile complete lists of all producers of coal, irrespective of size. Up to November 15, 1938, code acceptances had been received from more than 11,500 producers. A careful check of the acceptances has disclosed numerous mines not previously listed by either Federal or State mine departments. Included among the mines are some consumer-owned mines, commonly called "captive mines." These captive mines are owned by relatively few consumers, such as iron and steel companies. Nevertheless, the tonnage produced during good years is a considerable proportion of the total. In 1929, captive mines proper produced almost 18 percent of the total bituminous coal, and mixed captive and commercial mines produced an additional 9 percent.[25]

Total investment in coal mining probably is $2,500,000,000 to $3,000,000,000. The figures on investment are difficult to interpret, owing to the lack of definite and uniform appraisal of mining property. Reasonably accurate figures are available, however, for the anthracite industry. At the end of 1936 a total of $407,000,000 investment in anthracite lands, deposits, and other property and equipment which was used or useful in the production of anthracite was reported.[26] It is interesting to observe that much more than half the total investment consists of the estimated value of anthracite lands and deposits. The figure for this investment is 250 million dollars, whereas that for other property and equipment is only 157 million dollars. Much less reliable information on investment is available for the bituminous coal industry. It is possible, however, to piece together from various sources fragments of information bearing on investment.[27] If this be done, a figure ranging from 2 billion dollars to 2½ billion dollars appears to be a reasonable estimate.

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[21] *Report of the Anthracite Coal Industry Commission*, Commonwealth of Pennsylvania, Harrisburg, June 30, 1938, pp. 277 and 321-416.

[22] *Ibid.*, pp. 277–278.

[23] Based on data in *Minerals Yearbook, 1938*, p. 711.

[24] *Minerals Yearbook, 1938*, p. 712.

[25] J. P. Williams, Jr., "Organization of the Production, Processing and Distribution of Coal and Coal Products," *Third World Power Conference*, Washington, 1936, section II, Paper No. 4, p. 7.

[26] *Report of the Anthracite Coal Industry Commission, op. cit.*, p. 279. These data agree relatively well with those reported by the Pennsylvania Department of Internal Affairs (*Report on Productive Industries, Public Utilities, and Miscellaneous Statistics, 1929*, p. 128) and with the earlier figures compiled by the United States Coal Commission (see *Report of the United States Coal Commission, 1925*, Part I, p. 74; Part II, pp. 935–940 and 945).

In years of active business, the coal industry commonly has an income exceeding 1 billion dollars. In 1929 the total value of coal at the mine was 1,339,000,000 dollars.[28] Of this amount, 386 million dollars represented the value of Pennsylvania anthracite at the mine, and the remaining 953 million dollars that of bituminous coal. Total value for 1936, the latest year for which data are available, was 994 million dollars, this being represented by 226 million dollars for Pennsylvania anthracite and 768 million dollars for bituminous coal.[29] The anthracite industry showed a net income until 1932. The consolidated net income for companies producing roughly nine-tenths of the total anthracite was 34 million dollars in 1926, 15 million dollars in 1929, and 9 million dollars in 1931.[30] In 1932, however, a deficit of about 11 million dollars was incurred. This deficit was curtailed somewhat in the succeeding years. In 1934 it was less than 2 million dollars, but in 1935 it increased to more than 10 million dollars.

Bituminous coal mines began to show annual deficits earlier than did the anthracite mines. The data reflecting on this point are not complete for all years; but it is known from the income tax reports that a deficit was incurred as early as 1925; and, even in 1929, a year of unusually active business, the returns showed a net deficit.[31] Losses increased during the depression until 1933, when a slight upturn was shown. The record for 1934 and 1935 was better than that for any preceding year except the predepression years. The bituminous coal industry showed an enormous net income during the period from 1917 to 1921. In fact, during this period, annual net income, according to the tax returns, averaged more than 100 million dollars per year.

Taxation

It is often contended that the coal industry bears an exceptionally heavy burden of taxation. The major portion of the taxes collected are State and local taxes assessed against coal lands and resources. Unutilized resources, therefore, must bear the burden of taxation the same as resources actually being worked. In 1935 State and local taxes in the anthracite industry amounted to 26 cents per ton out of a total production cost of $4.45 per ton, and in 1924 they were 28 cents out of a production cost of $5.47 per ton.[32] For a period of years, Pennsylvania levied a tonnage tax against anthracite production, but in 1932 the tax was discontinued.[33] Information assembled by the National Recovery Administration indicates that the per-ton tax bill of the bituminous coal industry is much lower than that of the anthracite industry. During the period from April 1934 to either December 1934 or January 1935 taxes on property and equipment in the bituminous coal industry amounted to approximately 3 cents per ton against a total production cost of approximately $2 per ton.[34] These figures on taxation indicate that a shift of the taxes from a resource basis to a tonnage-production basis probably would be possible without placing an excessive burden on current production.

Life Expectancy of Mines

The mortality rate among coal mines is notoriously high. Unfortunately, data collected do not reflect adequately this mortality, because they pertain principally to the larger and more stable mining companies. It is known, however, that each year a large number of mines are abandoned either temporarily or permanently.[35] The United States Coal Commission in 1923 made a study of the probable life of certain mines. It was found that the average life expectancy of bituminous coal mines, excluding abandonment, ranged from about 12 years in some of the western mines to about 46 years in the Alabama mines. Bituminous coal mines of West Virginia reported a life expectancy of 42 years; those in Maryland, Kentucky, Virginia, and Tennessee, 43 years; Illinois and Indiana, 32; Pennsylvania, 29; and Ohio, 24 years. The average age of the mines studied ranged from 11 years in the western fields to about 20 years in the older eastern fields.[36]

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[27] See the *Report of the United States Coal Commission, op. cit.,* Part IV, pp. 2519–2707, especially pp. 2528–2529. Pennsylvania Department of Internal Affairs reports for 1929 capital investment in the bituminous-coal industry of Pennsylvania amounting to $493 million; *Report on Productive Industries, Public Utilities, and Miscellaneous Statistics, 1929,* p. 128.

[28] *Minerals Resources, 1930,* Part II, pp. 614–15.

[29] *Minerals Yearbook, 1937,* pp. 794 and 868.

[30] *Report of the Anthracite Coal Industry Commission, op. cit.,* p. 316.

[31] Compilations of the U. S. Treasury Department. Cf. *Minerals Yearbook, 1938,* p. 697.

[32] *Report of the Anthracite Coal Industry Commission, op. cit.,* p. 317.

[33] *Ibid.,* p. 316.

[34] Williams, *op. cit.,* p. 43.

[35] N. G. Alford, *op. cit.,* pp. 476–88.

[36] *Report of the United States Coal Commission, 1925,* Part III, p. 1433.

Labor Problems

One of the chief problems of the coal industry is the excessive number of miners dependent on it for a living. Temporarily large demand during and immediately after the World War led to an oversupply of labor in the industry. Post-war labor disturbances in the old and more strongly unionized fields induced employment of new workers in nonunion mines. The declining trend in coal production and the increased mechanization of mines are further factors responsible for an excessive number of workers. Many of the difficulties of the industry, such as low wages, long hours, loss of time, poor standards of living, strikes, and restrictions of civil liberties have been attributable in part to the surplus of miners. With the exception of the past several years, the coal industry has had a poor labor record, the history being marred by numerous disputes between miners and operators. For many years unions have been attempting to improve the conditions of the miners. During and immediately after the World War the strength of the United Mine Workers of America increased rapidly. Even many of the decidedly nonunion fields were unionized. Failure to reach agreement in 1922 led to widespread strikes. The outcome was the breaking of the strength of the union in the southern fields but the raising of wages in the northern fields. In 1924 the relatively high level of wages in the unionized fields was continued by the so-called Jacksonville agreement, but defection of operators from the agreement began almost immediately. Northern fields rapidly lost tonnage, and many mines closed down and reopened later on a nonunion basis. By 1927 the strength of the United Mine Workers in the northern fields was materially reduced. During 1928–29 the union was weak in all except a few fields in Ohio, Illinois, and some of the mountain States. The union continued to lose strength during the early years of the depression, but even many operators desired its rehabilitation to stabilize the wage structure. Its revival dates from the inauguration of the codes under the National Industrial Recovery Act. Membership in the United Mine Workers increased from 57 percent of total employment in the bituminous coal industry in 1933 to 87 percent in 1934, and its status was converted from that of a weak organization to that of a potent factor in collective bargaining.[37] Further gains in strength were recorded under the Bituminous Coal Conservation Act of 1935, which was later declared unconstitutional by the Supreme Court. The Bituminous Coal Act of 1937 did not provide directly for unionization, but the elimination of this provision was not opposed by the union. This action apparently indicates a belief on the part of the union that it has sufficient strength to support its own demands under the National Labor Relations Act.

Almost revolutionary changes have occurred in wages and hours in the coal industry since 1933. In 1932 the normal operating schedule in the anthracite industry called for 48 hours per week, and a normal schedule in the bituminous coal industry was 48.6 hours.[38] Average full-time hours per week in the bituminous coal industry were reduced to 40 in 1933, to 35.1 in 1934, and to about 35 in 1937; whereas in the anthracite industry a schedule of 48 hours was maintained until May 1, 1937, when a 35-hour schedule was adopted. In the decade before the World War the work week consisted of 54 hours for unionized mines in the anthracite industry and of about 52 hours in bituminous coal mines. The anthracite industry worked on a 60-hour schedule until April 1, 1903, and the bituminous coal industry until the early part of 1897.

Current hours of work in the coal industry are much shorter than those in most other major industries. Owing to drastic reduction in hours, the argument for further limitations on the basis of physiological considerations seems to have lost most of its force, even though coal mining, it must be recognized, is arduous work.

Recent labor data, reported by the United States Bureau of Labor Statistics, indicate a highly favorable position for the coal industry with respect to average hourly earnings but a comparatively unfavorable position in terms of average hours of work per week and average weekly earnings. Average hourly earnings were 88.8 cents per hour in the bituminous coal industry and 90.8 cents per hour in the anthracite industry (not including bootleg mines which paid lower wages) during August 1938, whereas average hourly earnings in all manufacturing industries combined were only 62.9 cents.[39] A very different relationship is shown, however, in earnings and in working time. In these, the comparison is unfavorable to both the bituminous coal and the anthracite industries. Hours of work per week were only 23.6 for bituminous coal mines and only 18.6 for anthracite mines, against 36.3 hours for manufacturing. Average weekly earnings were $21.38 for bituminous coal and $17.35 for anthracite, against $22.84 for manufacturing.

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[37] Cf. National Labor Relations Board, Division of Economic Research, *The Effect of Labor Relations in the Bituminous Coal Industry upon Interstate Commerce*, Bulletin No. 2, June 30, 1938, pp. 40–46; also Williams, *op. cit.*, p. 10.

[38] Leo Wolman, *Hours of Work in American Industry*, National Bureau of Economic Research, Bull. 71, November 27, 1938, New York, p. 2.

[39] *Monthly Labor Review*, November 1938, pp. 1165 and 1169. Earnings in the bituminous coal industry were 79.5 cents per hour in the last quarter of 1924 and only 41.2 cents in February 1933 (F. E. Berquist and Associates, *Economic Survey of the Bituminous Coal Industry Under Free Competition and Code Regulation*, N. R. A. Work Materials No. 69, vol. I, March 1936, pp. 1–2). The data on average hours in coal mines do not include time spent (average about 45 minutes) in going to and from the mine face (Cf. *Monthly Labor Review*, November 1937, p. 5).

If it be accepted that the average skill required for coal mining is not higher than the average skill required of labor in manufacturing, the higher average hourly earnings in the coal industry are explained not on the basis of reward for skill but solely on the basis of greater bargaining power. In any event, the unemployment problem among coal miners is considerably more pronounced than that in other industries generally. In fact, somewhat extensive unemployment of miners existed before the onset of the general depression after 1929.

In general, the tendency in the coal industry, during the past several years, has been toward rapid reduction of hours and rapid increases in hourly wage rates. Since the bituminous coal industry was incurring deficits in previous years, none of the increase in wage costs could be absorbed by the operators. The higher rates have, undoubtedly, attended higher coal prices; they have encouraged a shift to competing fuels; and they have encouraged the introduction of labor-saving mechanical equipment into mines, thereby resulting in further unemployment. A similar rise in unit wage rates of laborers employed in the production of mine equipment and of laborers employed in the production of competing fuels would, of course, tend to restore the balance of competition existing previously.

These comparisons of wage rates, of course, do not indicate that a complete reversal of policy should be introduced, but they do indicate that, if a balanced development of energy resources is to continue, action taken in the coal industry should be accompanied by equally effective action in competing industries. This factor is of paramount importance in attempts to provide a stability for the coal industry sufficient to enable conservation measures to be introduced. It seems clear that the problem of unemployment in the coal industry cannot be rectified within the industry itself. It is inconceivable that consumption of coal can be stimulated sufficiently by any practicable devices to lead to reemployment of all unemployed miners. Reduction of prices will not result in expansion of demand adequate to provide the industry a larger income for distribution among a larger employed mine population. Increase of prices, on the other hand, results in further loss of markets to competing fuels.

Mechanization

Coal operators are continuously seeking ways of reducing costs, and this search leads to the introduction of technological improvements. Coal mining used to be largely a hand operation. There has been a trend, however, toward increasing mechanization of production (fig. 16).[40] One of the earliest types of mechanization is represented in machines developed to cut the coal preparatory to breaking it loose from the bed. This type of mechanization has had a steady development. In 1913, 50 percent of the bituminous coal mined underground was cut by machines. By 1920 the percentage had increased to 60, and, at the present time, it is about 85. Less than 10 percent of the bituminous coal taken from underground workings is now mined by hand. Some bituminous coal, also, is shot off the solid bed without preliminary cutting either by machine or by hand. The percentage, however, is decreasing rapidly as is indicated by the fact that, in 1920, 16.9 percent was shot off the solid, whereas, in 1936, only 4.4 was broken loose that way. Machine methods for cutting coal are applied much less extensively in anthracite mines than in bituminous coal mines, for the reason that the beds are more irregular

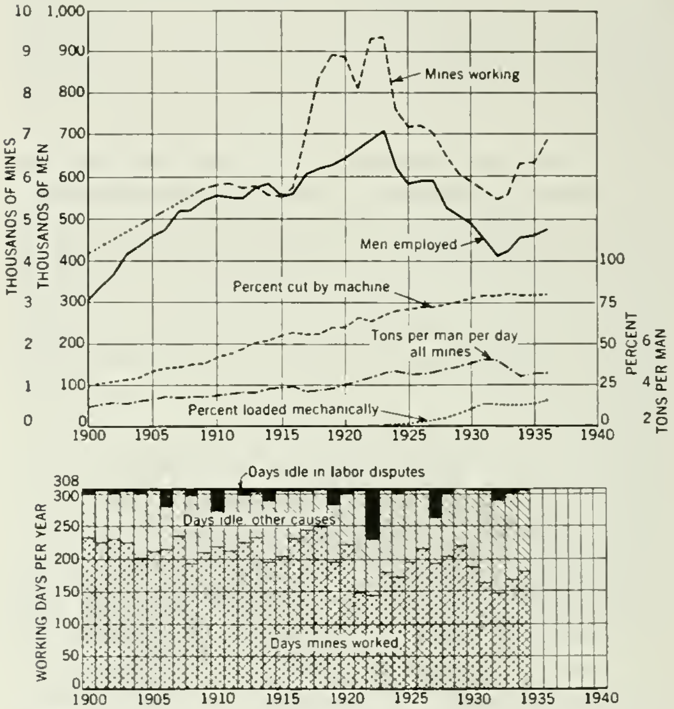

FIGURE 16.—Employment, Working Time, Mechanization, and Output Per Man at Bituminous Coal Mines, 1900–1937. (Reproduced from *Minerals Yearbook, 1938*, p. 714.)

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[40] Extensive tabulations of recent data on mechanization are given in *Coal Mine Mechanization Yearbook, 1938*, pp. 65–78.

and the coal is much harder. Less than 5 percent of the anthracite taken from underground workings is cut by machine.

Electrification of mine haulage is another form of mechanization that has made rapid strides in the postwar period. Main-line haulage is electrified in nearly all the larger mines. Electrification not only permits more rapid haulage but it also enables haulage of larger tonnages on each trip. Although electrified haulage is widely used for gathering mine cars from the various working places, mules, horses, or ponies are still used for that purpose in many mines. There is also some other mechanized haulage, such as that with gasoline tractors.

One of the most advanced forms of mechanization of mining is represented in the strip, or open pit, mines. These mines are mechanized almost 100 percent. Large power shovels are used to remove the overburden of rock and soil, and smaller power shovels are used for loading the coal into cars. Handwork, if it exists at all, usually is limited to clean-up work. Introduction of larger and more powerful shovels has enabled strip mining to reach coal at greater depths. As a result, the proportion of bituminous coal mined in this way increased from 1.6 percent in 1920 to 7.0 percent in 1936. Electrification has played an important part in strip mining as it has in underground mining. Electric shovels are increasing in number as well as in size, whereas the use of steam shovels is declining rapidly.

Until the early 1920's, almost all the coal mined was loaded by hand. Mechanical loaders began to attract wide attention in 1923. In that year the amount of bituminous coal loaded by the machines was slightly less than 2 million tons. In 1929 mechanical loading in bituminous coal mines amounted to 38 million tons. Although the actual tonnage handled by the machines in the several subsequent years did not increase substantially, the percentage of total tonnage handled showed a large gain, owing to the recession in total mining. Since 1934 not only the total tonnage handled by loading machines has increased but also the proportion of the total. The percentage of underground tonnage handled in bituminous coal mines rose from 12 in 1934 to 19 in 1937, and the actual tonnage increased from 41 million in 1934 to 83 million in 1937. Conveyor loading is more important in anthracite mines than in bituminous coal mines, but the machines are relatively simple; the more highly mechanized mobile loaders are not used.

Rapid gains in mechanized loading have occurred in the bituminous coal mines since improvements have been made in the mobile loaders. The number of these loaders in bituminous mines increased from 488 in 1929 to 534 in 1934 and to 980 in 1936. Further increases are indicated for 1937, owing to the fact that 292 additional machines were purchased in that year. Hand-loaded conveyors also are showing marked increases in bituminous mines, the number of such conveyors having risen from 525 in 1933 to 936 in 1936. The total number in 1936 of all types of conveyors in bituminous coal mines was 1,170, but purchases in 1937 alone amounted to an additional 835 machines. A different condition exists in the anthracite mines, in which no mobile loaders are used. There were, in 1936, 1,790 conveyors, usually of simple design, in use in such mines, but purchases in 1937 amounted to only 260 machines in contrast with the 835 machines for bituminous coal mines. Scrapers are used extensively in anthracite mines. There were 504 in use in 1936 against only 106 in use in bituminous coal mines.

The introduction of mechanized loading will have widespread effects on employment. Because hand loading is the largest single source of employment in mines at the present time, the introduction of machines will displace a large number of miners. Although more persons will be employed in the manufacture of machines, it is unlikely that the displaced miners will shift to machine making. Consequently, mechanization of loading will have a disrupting effect on employment.

Mechanical methods of loading have the disadvantage of loading rock and other debris as well as loading the coal. There is little opportunity for the miners to pick out the debris before the coal is loaded on the cars. As a result, it has become necessary to introduce more extensive cleaning of the coal after it has been brought to the surface. Cleaning of coal, as it is done at the present time, is mechanized to a very large extent. The amount of bituminous coal cleaned in 1929 was 37 million tons, and there were some gains during the depression. By 1935 the tonnage was about 45 million. Since then, gains have been accelerated. In 1937 a total of 65 million tons of bituminous coal was cleaned by mechanical methods. About five-sixths of the total was cleaned by wet methods and the remaining one-sixth by pneumatic methods. The 65 million tons is 15 percent of the total production in 1937. The percentage of coal mechanically cleaned varies markedly from State to State. In 1936, 81 percent of the Alabama coal and 66 percent of the Washington coal was so cleaned, whereas, in the two leading producer States, the percentage was considerably smaller. The proportion in Pennsylvania was only 20 percent and that in West Virginia only 13 percent.

Preparation of coal long has been a part of the regular routine of the anthracite industry. The comparatively large percentage of slate and other impurities mixed with anthracite makes it necessary to pick out such impurities by hand, especially where it adheres to the coal, or to separate it by mechanical methods.

Sizing of coal is almost completely mechanized, and the possibility of further mechanization is limited, therefore, to the introduction of equipment capable of handling larger tonnages.

On casual observation, it may appear that the possibilities of mechanization in the coal industry are almost limitless. More careful study, however, indicates some very definite limitations. Lack of uniformity in the occurrence of coal is undoubtedly a handicap to mass production methods. Anthracite mines are, as a rule, less mechanized—they use simpler machines—than bituminous coal mines, for the reason that the occurrence of the coal is much more highly variable. Accordingly, the possibilities of mechanization are conditioned by the extent to which beds of relatively uniform coal can be found. Exhaustion of the better beds will increase the problems of mechanization. It is true, nevertheless, that mechanization will be the most economical means for recovering inferior beds and will become an increasingly important factor in their recovery.

Transportation of Coal

Production and transportation of coal are interdependent. Coal constitutes more than one-third of the carload freight tonnage of railroads and usually yields 20 to 25 percent of the total carload freight revenue. On the average, the railway freight bill for the portion of bituminous coal actually shipped as revenue freight exceeds the mine price. In 1936, for example, the average railway freight on bituminous coal was $2.25, whereas the average value of the coal at the mine was $1.77. Anthracite has a higher value per ton, but, because of nearness to New York City and other eastern markets, it is hauled shorter distances. The average value at the mine in 1935 was $4.29, and the average railroad freight was $1.66 per ton.

In 1936, 84 percent of the bituminous coal was shipped by railroad, slightly less than 6 percent by river, and slightly more than 6 percent by truck or wagon; use at the mine for power, heating, or coke making accounted for a little more than 1 percent of the total; and sales to local trade, amounts used by employees, and loadings by locomotives at the tipple accounted together for a little more than 2 percent of the total. Anthracite shows similarly small percentages for coal used at the mine; the remainder is shipped largely by rail, although trucks are used, especially for the more than 2,000,000 tons of bootleg coal.

In 1935 the average length of haul of bituminous coal by railroads was 188 miles, whereas that of anthracite was 116 miles. All commodities combined were transported 199 miles. Fruits and vegetables, to point out one contrasting example, traveled 481 miles. An average carload of bituminous coal was 52 tons and of anthracite 49 tons. The tonnage varied considerably among the regions. In the Pocahontas region, for example, the average load was 58 tons, whereas in the western region it was only 44 tons. A comparatively small dead weight is involved in the transportation of coal. The weight of the car constitutes about 30 percent of the combined weight of the car and the coal. Among other commodities, the weight of the car, on the average, considerably exceeds the weight of the commodities.

There are very few commodities for which the ratio of freight to the value of the commodity is higher than for coal. In 1935 this ratio was 123 percent for bituminous coal. In contrast with this high percentage is the percentage of only 11 for agricultural products. This high ratio for coal, of course, reduces the burden of claims for damages. For bituminous coal these claims are usually less than 16 cents for each hundred dollars of revenue obtained for coal transportation.

Trucking of coal has been encouraged by relatively high railroad freight rates for short hauls. Long hauls pay proportionately much lower rates than do the shorter hauls. The freight rate per ton-mile between the Belleville, Ill., producing district and St. Louis, a distance of 15 miles, was, before the imposition of emergency increases, 70 mills per ton-mile. On the other hand, the rate for coal transported between the Pocahontas, W. Va., district and Chicago, a distance of 582 miles, was 5.31 mills per ton-mile.[41]

Large tonnages of coal are shipped from the Appalachian fields to Lake Erie for trans-shipment by lake. Freight rates for shipments from the producing fields to the lower lake ports, therefore, indicate what effect the freight-rate structure has on the shipment of these comparatively large tonnages. The rate from the Ohio No. 8 field to Toledo is $1.43, and the average haul is 185 miles. The rate from the Pittsburgh field to Ashtabula, Ohio, is $1.46, and the average haul is 159 miles. That from the McRoberts field in Kentucky to Toledo is $1.81, and the average haul is 471 miles. In these rates no account is taken of the emergency charges introduced in recent years. In the *Holmes and Hallowell* case, the Interstate Commerce Commission prescribed a mileage scale for transportation of bituminous coal.[42] On the long hauls, those exceeding about 130 miles, the scale calls for an additional charge of about seven-tenths of a cent per ton per mile for additional distances. Rates such as those established for the shipments to the lakes, of course, almost completely disregard an approximate mileage scale such as that established in the *Holmes and Hallowell* case. The United States Coal Commission in 1923 called attention to the tendency of the freight-rate structure to favor the more distant fields. In general, fields in Illinois, Indiana, Ohio, northern West Virginia, and Pennsylvania are denied the advantage in the freight-rate structure of favorable location with respect to markets. Some readjustment of freight rates has been made since the 1923 report. The changes, however, have been of minor importance. The conclusions of the Commission, therefore, are as applicable at the present time as they were when the report was issued.

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[41] W. H. Young, "Truck Movement of Coal from Mines," reprint from *Proceedings of Third Pennsylvania Minerals Conference (Coal Section), November 10–11, 1933*, Pennsylvania State College Bulletin 15, p. 6.

Storage

Bituminous coal is stored almost exclusively by carriers, retail dealers, and consumers. Anthracite, on the other hand, is stored to some extent in producers' storage yards. At the beginning of 1938, for example, 2,150,000 tons of anthracite were stored in the hands of producers. There is also some storage of both bituminous coal and anthracite at lake docks.

Electric public utilities, byproduct coke producers, steel companies, manufactured gas companies, cement plants, and railroads keep on hand large stocks of bituminous coal. Total stocks of bituminous coal in the hands of industrial consumers amounted to 39,000,000 tons at the end of 1937. There were also at that time slightly more than 8,000,000 tons at commercial docks on Lake Superior and Lake Michigan. Coal in transit also constitutes a form of storage which normally accounts for more than 9,000,000 tons.

Storage of coal varies considerably, depending on the seasons of the year. Stocks nearly always increase during the last half of the year and decrease during the first half. A low point ordinarily is reached at the same time that production is at low ebb. Seasonal swings are sometimes accentuated by the fear of consumers of a shortage during the peak months of the year. Storage is usually large when there are threats of strikes, and, of course, actual suspensions are usually preceded by accumulation of stocks. As far as can be determined, storage has no leveling effect on the cyclical fluctuations of coal production. On the contrary, stocks are usually at low ebb during a period of depression and at a peak during a period of prosperity. Consequently, cyclical fluctuations in the accumulation and depletion of stocks tend to aggravate cyclical fluctuations in production.

It is probably not practicable to attempt to obliterate the fluctuations in coal production by storage. Coal is extremely bulky, and storage capacity, sufficient to have a marked effect on production, would require a prohibitive investment. Furthermore, storage of bituminous coal is attended by risk of spontaneous ignition, and it also results in degradation or loss of heat value of the coal. In this connection it is interesting to note that in Japan an attempt has been made to prevent deterioration of coal by shortening the period of storage.[43] Anthracite may be stored for long periods without any appreciable loss of heat value, and the same thing is true of coke. Conversion of bituminous coal to coke, therefore, results in some conservation, owing to the fact that deterioration during the period of storage is reduced. The use of the highest rank bituminous coals for coking, however, is an unfavorable feature.

Markets for Coal

The market radius for coal for each of the main producing areas is determined by numerous factors involving differences in the nature of the coal, needs of consumers, production and transportation costs, and promptness of delivery.[44] Because of the bulkiness of coal and its low value, the market tends to be localized except where low-cost transportation, such as that existing on the Great Lakes or along the Atlantic coast,

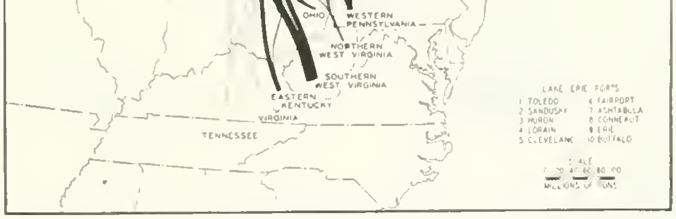

FIGURE 17.—Lake Cargo Shipments of Bituminous Coal, 1929. (Reproduced from Fritz and Veenstra, *Regional Shifts in the Bituminous Coal Industry*, p. 72.)

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[42] *Holmes and Hallowell Co.* v. *Great Northern Railway Company*, 60 I. C. C. 687, and 69 I. C. C. 11.

[43] T. Yamada, "Use and Transport of Coal by the Japanese Government Railways," *Third World Power Conference*, Washington, 1936, sec. II, Paper No. 4, p. 19.

[44] Cf. W. H. Young, "Distribution of Coal," *Proceedings, Third International Conference on Bituminous Coal*, Pittsburgh, 1931, vol. 1, pp. 142–56.

is available. As a result of the intense competition in the industry, producers often have entered the market of competitors having transportation advantages. The freight-rate structure, in conjunction with the differences in production costs, also has modified the market areas for competing coal producers. Differences in quality of coal in one region against those of another sometimes lead to marked differences in the length of haul. As a rule, coal of high quality will bear a higher transportation charge than coal of low quality.

Certain focal points of competition have been developed. There is severe competition by rail routes for the markets of Ohio. Consuming areas adjacent to the Great Lakes also are subject to extreme competition, and the same is true of areas along the Atlantic coast (figs. 17 and 18). In 1929, when 537 million tons of bituminous coal were produced, 36 million tons were shipped to tidewater ports, 39 million tons entered the Great Lakes trade, and 120 million tons were railroad fuel delivered by all-rail routes.[45] In that year 74 percent of the bituminous coal produced entered interstate traffic or was used as railroad fuel. Numerous producing States shipped coal to a score or more consuming States. Kentucky coal was shipped to at least 32 States and to the District of Columbia.

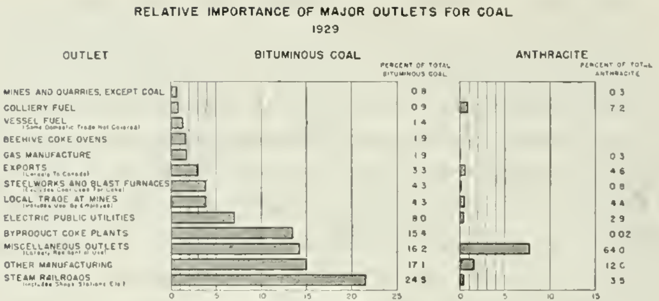

FIGURE 19.

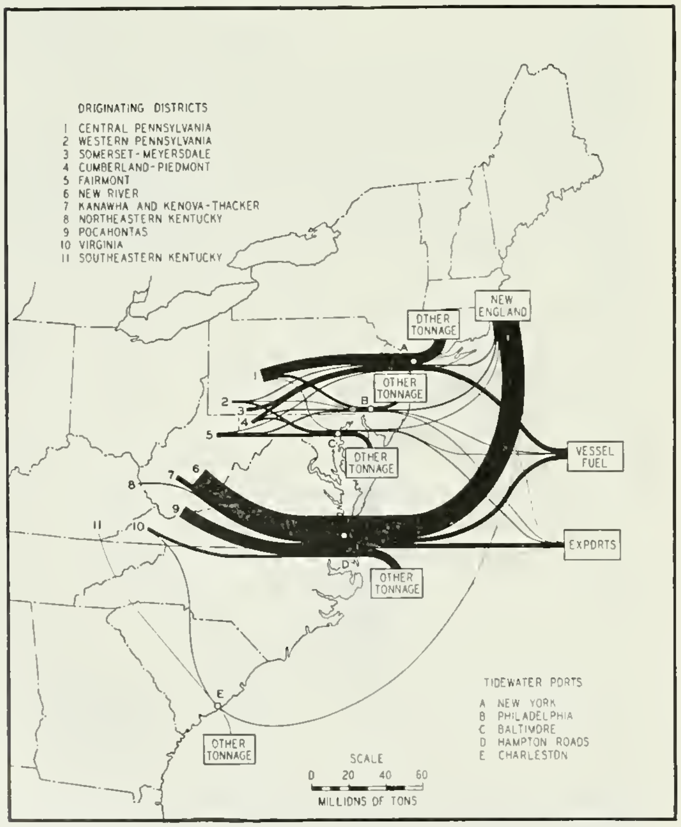

FIGURE 18.—Tidewater Shipments of Bituminous Coal, 1929. (Reproduced from Fritz and Veenstra, *Regional Shifts in the Bituminous Coal Industry*, p. 89.)

Since the World War, there have been disturbing regional shifts in production. Many of the western States have shown declining production, mainly because of increasing competition encountered from the oil and gas industry. In the northeastern market, shifts have taken place because of the variable incidence of competition within the coal industry in addition to whatever competition has come from oil and gas. The Ohio, Illinois, and Indiana bituminous coal regions and the Pennsylvania anthracite region have shown extremely heavy losses in production. Somewhat smaller losses have been encountered in the Pennsylvania and northern West Virginia bituminous coal areas. Even within small producing regions wide differences in trend of output have appeared. The central and northern Pennsylvania bituminous coal areas, for example, have suffered unusually severe losses of output, whereas the western Pennsylvania producing area has held its position much more effectively.

Steam railroads are the largest single class of consumers of bituminous coal. In 1929, locomotive fuel accounted for about 22 percent of the total coal consumption. Domestic (residential) consumption is probably about 12 percent of the total. Manufacturing industries are also ravenous consumers of bituminous coal. All classes of manufacturing concerns combined show a considerably larger consumption than the total consumption by steam railroads.

In sharp contrast with this character of the consuming market for bituminous coal is the market for anthracite. More than three-fifths of the anthracite produced in 1929 was taken by domestic consumers. Although manufacturing plants consumed an appreciable tonnage of anthracite, the proportion taken by such plants was a relatively minor share of the total. Only a little more than 2 percent of the anthracite is taken by steam railroads, despite the fact that the majority of the anthracite production is controlled by railroad companies and that there is extremely dense railroad traffic in and near the anthracite region. The importance of

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[45] F. G. Tryon and W. H. Young, *Distribution of Bituminous Coal Classified as Interstate, Intrastate, and Railroad Fuel, 1929*, United States Bureau of Mines, Supplement to Monthly Coal Distribution Report, No. 58 (mimeographed).

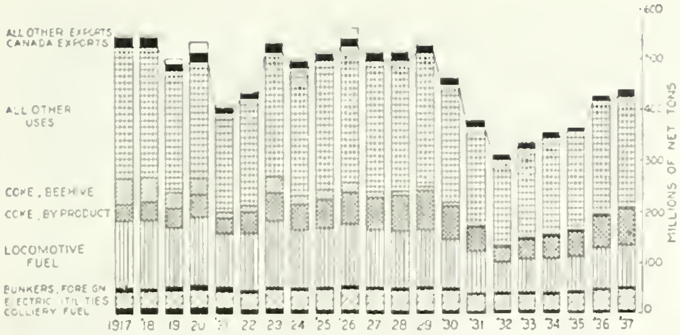


FIGURE 20.—Tonnage of Bituminous Coal Entering Each of the Major Branches of Consumption, 1917–37. (Reproduced from *Minerals Yearbook, 1938*, p. 691.)

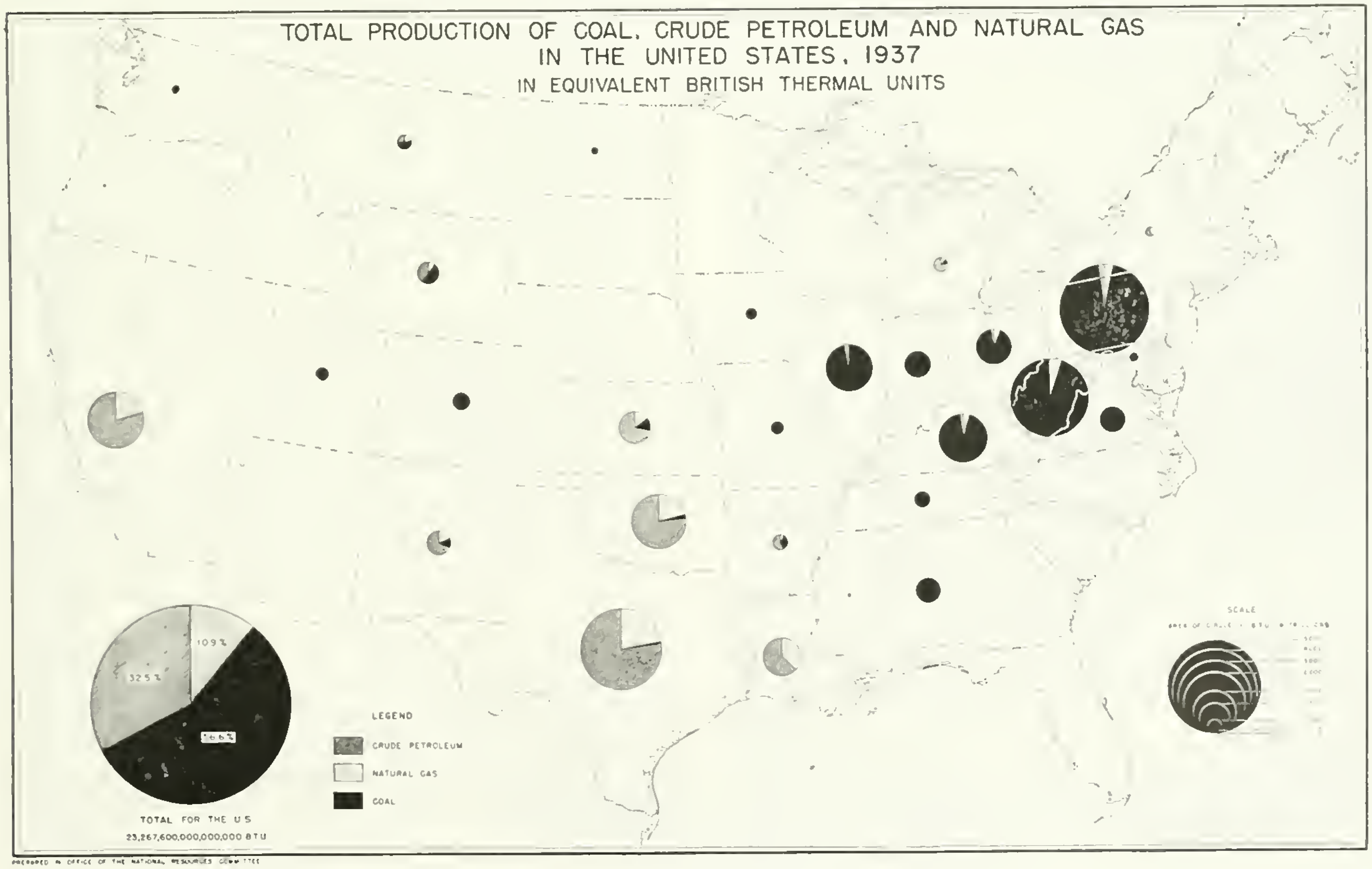
various major outlets for coal is indicated in figures 19 and 20.

Competition with Other Fuels

In addition to competition within the coal industry, there is also severe competition at numerous points with other fuels. This question is discussed at length in the next chapter. It is sufficient to observe here that the distribution pattern of the coal industry is conditioned by this outside competition (fig. 21). Coal mines have been able to retain their market relatively well in and near the major coal-producing sections, but they have suffered severe losses to oil, natural gas, and water power. Oil and gas competition has been largely west of the Mississippi River. Within recent years pipe lines have been extended eastward, however, and an increasing amount of competition is being encountered, especially in Illinois and Indiana. There is also considerable competition along the Atlantic coast because of the use of tankers for low-cost transportation of oil from the Gulf coast oil fields.

Price History

Except for brief periods under the National Recovery Administration, the Coal Act of 1935 and the Coal Act of 1937, bituminous coal prices have been determined by competitive forces. Accordingly, the price of bituminous coal has fluctuated with every shift in the competitive balance. Retail prices of bituminous coal in 38 cities reached a peak of $11.15 a ton in 1921, according to the Bureau of Labor Statistics. The average in 1929 was $8.85. A low point of $7.65 was reached in 1933. In the ensuing years there has been a gradual recovery, the average price in 1937 being $8.58, a figure somewhat lower than that for 1929, despite the fact that the coal industry has made marked advances in wage rates. These figures, of course, cover domes-


TOTAL PRODUCTION OF COAL, CRUDE PETROLEUM AND NATURAL GAS
IN THE UNITED STATES, 1937
IN EQUIVALENT BRITISH THERMAL UNITS
10.9%
32.5%
56.6%
TOTAL FOR THE U S
23,267,600,000,000,000 BTU
LEGEND
CRUDE PETROLEUM
NATURAL GAS
COAL
SCALE

PREPARED IN OFFICE OF THE NATIONAL RESOURCES COMMITTEE

FIGURE 21.

tic sizes; they do not include screenings, which sell at low figures and are a considerable percentage of output.

Anthracite prices show the stair-step type of fluctuation characteristic of monopolistic pricing. During 1937 the circularized mine price of buckwheat No. 1 anthracite was maintained without variation at $3.25 per ton, and the quoted price of stove-size anthracite was maintained continuously for periods of several months at a time without change. Prices for coal vary markedly among consuming regions. This wide variation exists because of the heavy expenditure for transportation and the regional concentration in the distribution of commercially minable reserves. This regional variation is illustrated in the diversity of prices paid by retail purchasers in various cities throughout the country. The Bureau of Labor Statistics gathers such information monthly. On September 15, 1938, eastern high-volatile bituminous lump coal sold for $4.66 per ton delivered at retail in Pittsburgh. The price for similar coal in Chicago was $9.95 per ton. The stove-size of anthracite sold for $7.65 at Scranton, Pa., whereas the price in Chicago was $14.70. These differences, of course, tend to be reduced whenever supplies of coal can be drawn from a competing area.

Foreign Trade in Coal

Imports of bituminous coal and anthracite nearly always have been small in relation to domestic production. Foreign trade in coal is erratic, because of the effect of interruptions of production either in the United States or in the foreign countries. Exports of coal were markedly expanded, for example, in 1920, owing to restrictions on exports from British mines, and they were expanded again in 1926 when there were widespread strikes in British mines (fig. 22). The United States imported considerable tonnage of coal in 1922, when prolonged strikes interrupted production in domestic mines. Total annual imports of bituminous

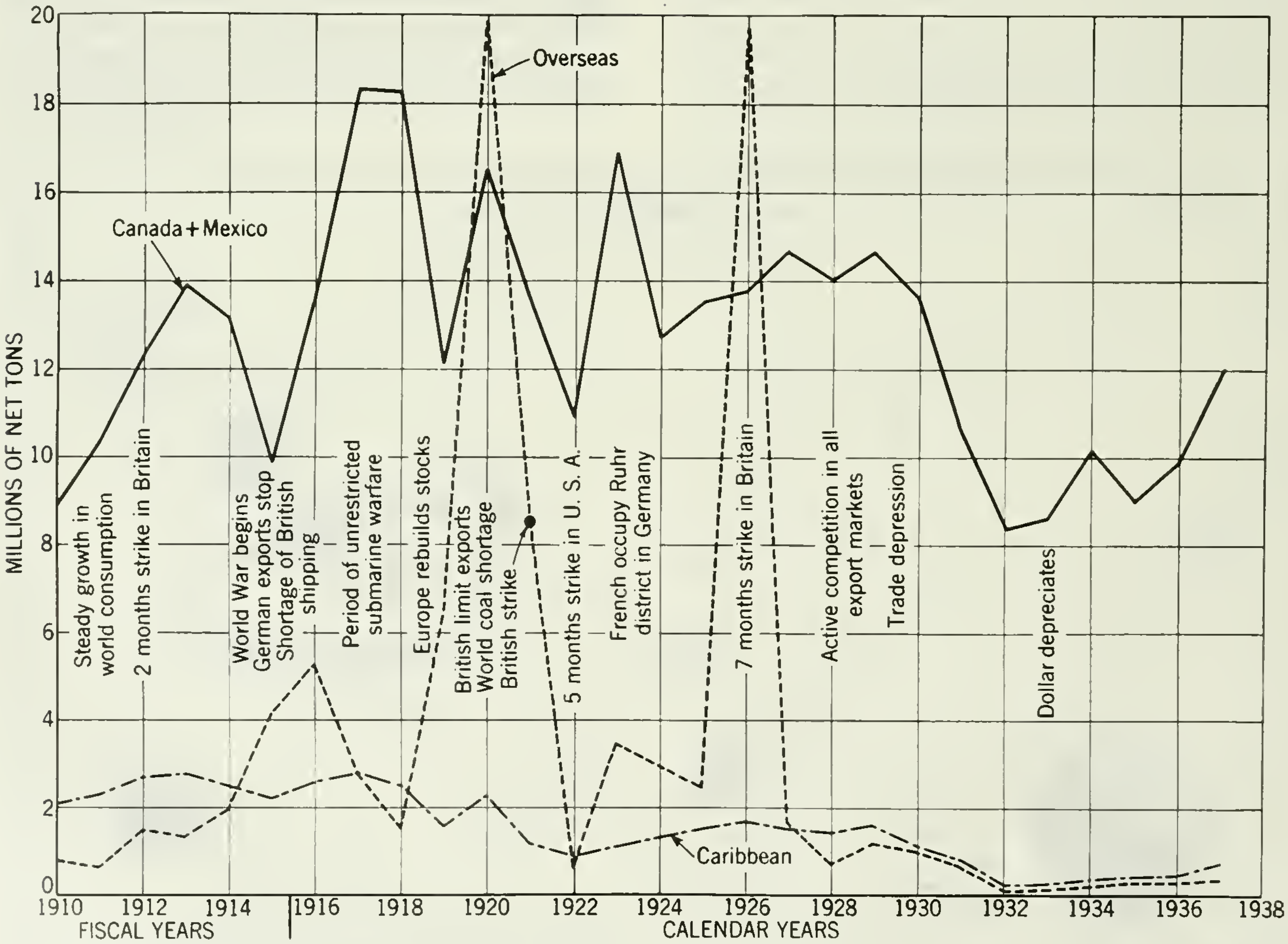


FIGURE 22.—Exports of Bituminous Coal to Canada and Mexico, the Caribbean, and Overseas Destinations, 1910–37. (Reproduced from *Minerals Yearbook, 1938*, p. 724.)

coal usually have been little, if any, above 500 thousand tons in recent years, and the same statement applies to anthracite. Exports, on the other hand, of both bituminous coal and anthracite are considerably larger. In 1937, exports of bituminous coal amounted to 13,000,000 net tons and exports of anthracite amounted to 1,900,000 tons. The export surplus (exports less imports) of bituminous coal has ranged from 2.5 to 3.3 percent of total output in recent years; the anthracite export surplus amounted to 1.2 to 2.9 percent of production in the years 1930–37. The bulk of the coal exported goes to Canada. In recent years, Canada has usually taken more than nine-tenths of the total coal shipped to foreign countries. Approximately half the coal sent to Canada leaves the United States by way of the Lake Erie ports of Ohio, and nearly all the remainder is transported by way of the St. Lawrence or through the Rochester, Buffalo, or Michigan gateways. Nearly nine-tenths of the exports come from the Appalachian fields.

The United States exports some coke to foreign countries. Approximately 95 percent of the total is shipped to Canada by way of the Great Lakes. Domestic exports of coke have averaged about one and seven-tenths percent of the total produced. Exports of coke are usually five times as large as imports.

Total imports of anthracite usually have amounted to about 1 percent and exports from 3 to 5 percent of production in the United States. Imports have come mainly from the Soviet Union and the United Kingdom (also reexports from Canada), and they have entered principally in ports in New England, an area which consumes approximately 10 percent of the domestic shipments of anthracite. Exports are sent largely to the Canadian provinces of Ontario and Quebec.

The Tariff Act of 1913 placed all varieties of coal on the free list.[46] The Tariff Act of 1922 continued all coal on the free list, but provided that "if any country, dependency, province, or other subdivision of government imposes a duty on any article specified in this paragraph (1548), when imported from the United States an equal duty shall be imposed upon such article coming into the United States from such country, dependency, province, or other subdivision of government."

The conditional duty provision in the Tariff Act of 1922 was reimposed by the act of 1930. This conditional duty, however, was repealed by the Trade Agreement Act, which became effective June 12, 1934.

The Revenue Act of 1932 provided for an import excise tax of 10 cents per 100 pounds on coal imported into the United States from countries to which exports of coal from the United States did not exceed in the previous calendar year, the imports of coal therefrom, unless "treaty provisions of the United States otherwise provide." The excise tax on imported coal imposed by the Revenue Act of 1932 has been extended to June 30, 1939. Treaty provisions which "otherwise provide" are those arising out of a most-favored-nation clause, such as exists in commercial treaties of the United States with Belgium, the United Kingdom, and Japan.

In recent years most of the imports of coal and coal products have come from the Soviet Union, the United Kingdom, Canada, Germany, and Belgium. Imports from all of these countries, except Germany, now enter the United States tax free. In 1937 all the bituminous coal imported into the United States was tax free, and about four-fifths of the coke imported was also tax free. On the other hand, almost half the anthracite was taxable, and the remainder was tax free.

Possible Future Sources of Coal Outside the Continental United States

Most of the possessions of the United States are relatively devoid of coal. Alaska is an exception to this general rule. Coal production in Alaska was only 137 thousand tons in 1936, an amount insufficient to provide for consumption there. It is known that there are extensive Alaskan deposits, ranging from lignite coal to anthracite.[47] Little prospecting or development work has been done, because of the relatively small demand. An abundance of oil along the Pacific coast of the United States has discouraged attempts to ship the Alaskan coal to continental United States. The coal reserves are, in many instances, relatively close to the sea coast. At some future time they may become an important factor in trade.

There are extensive deposits of coal in Canada which may sometime become a source of fuel for industry in the United States. The most accessible Canadian coal resources are concentrated in five major areas. Deposits of good coal are found at the water's edge of Cape Breton Island, at the north end of Nova Scotia. This coal is within easy reach of cheap water transportation and may sometime become important in the trade along the Atlantic coast. At the present time, however, production costs are relatively high, and the coal does not compete effectively with that produced in the United States.[48] There are lignite deposits in the

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[46] This résumé of tariff legislation on coal has been provided for this study by the United States Tariff Commission

[47] National Resources Committee, *Regional Planning, Part VII*, p. 209.

[48] The B. t. u. value of the Cape Breton coal is only 13,100. Operating cost in 1935 was $4.06 per ton, a figure about twice as high as that for Appalachian bituminous coal in the United States. B. F. Haauel, "Organization of Production, Processing and Distribution of Coal and Coal Products in Canada," *Third World Power Conference*, Washington, 1936, Sec. II, Paper No. 4, p. 8.

Canadian plains area. These deposits are an extension of those in North Dakota and Montana. Somewhat farther west are extensive resources of low-rank bituminous coal, and these also constitute an extension of coal deposits found in Montana. There are scattered bituminous coal fields north of the State of Washington not far from the international boundary. Numerous small fields also are found near the Pacific coast, either on islands or in the inland mountain areas.

These resources of coal outside continental United States should be viewed only as a possible source for the remote future. Mines in continental United States have not reached such an advanced stage of exhaustion that they will not continue for a long time to supply nearly all of the Nation's coal requirements.

CHAPTER 4.—OPPORTUNITIES FOR CONSERVATION AND BETTER UTILIZATION

The Problem of Conservation

The search for a rational coal conservation policy is concerned with determining which measures among the many available will yield maximum benefits from the resources. It is agreed generally that unrestricted exploitation of coal resources will inflict heavy penalties at a later date in the form of diminished standards of living. It is equally true that conservation may be carried to the extreme of markedly depressing the present for the sake of the future. Somewhere between the two extremes a basis may be found for a reasonable solution.

Two aspects of conservation may be discussed at this point: one is reduction of the quantity of coal energy used; and the other is expansion of the amount of work, or output, derived from a given portion of the resources, the aim being to accomplish more with what is available.

Conservation by Reduction of Use

The first aspect assumes abstinence from use. This form of conservation is not new. It is applied in the preservation of wild game by a ban on hunting, trapping, and fishing except during a declared open season. Undeniably, such conservation has preserved many species of wild game from complete extermination, and it has usually increased the quantity of game at large. The common prohibition against picking wild flowers in public parks to preserve them for the enjoyment of a larger group of the populace represents a modification of the abstinence idea. Coal, of course, differs from these illustrations in that it is not reproducible. This lack of the possibility of replacement makes decreased use all the more urgent when any significant part of the coal reserves approaches exhaustion. In a sense the United States, and for that matter, the world, is "stranded" with a limited supply of mineral fuels. No one knows when a rescue party in the form of better sources of energy may arrive. In the light of experience thus far with substitute sources, encouraging signs have not been sighted. But the situation with regard to the total coal reserve is not precarious. If we are willing to make an increasing cost sacrifice for coal mining, enough coal can be obtained to last for hundreds of years. What is important in the short run is the exhaustion of the best ranks of coal in the most readily minable beds near areas of large consumption.

Conservation of Higher Ranks of Coal

The principle of substitution of a more abundant energy for a less abundant energy where cost differences are not marked is one that needs to be applied generally. The objective of a rational energy policy is maximization of the effective work derived from whatever energy-providing materials are available. Coal is only one of the several types of energy materials to be considered. A distinction also should be made among coals of various ranks and accessibility. The use of the less abundant high-rank coal for uses about as easily and adequately served by the more abundant low-rank coal is a questionable practice. Individual concerns or regions will, of course, always oppose action that reduces their market and favor action that expands it. But the problem is not primarily to decide what group is to benefit or incur disadvantage from the direction given to energy use; it is to derive the greatest total usefulness for the expenditure involved in appropriating the energy. One of the conspicuous features of our coal utilization has been rapid depletion of high-rank coal in the most available beds and neglect of low-rank resources, even though such coal is often easily mined. Larger use of low-rank coal could be an effective defense against high-mining costs in the future for specific ranks of coal required for specialized uses, such as the production of metallurgical coke. The rapid depletion of the best coking coals already has been pointed out. Coking coal has been and is at present being used for types of consumption that do not require such a rank of coal. The pressure of competition leads currently to exploitation of coal resources irrespective of future needs for specific ranks and types. Nature has provided us with a comparatively wide range of fuels—solid, liquid, and gaseous—from which to select those best adapted to various needs. The method of exploitation, on the other hand, is rapidly reducing the range of options and is thereby adding to the problem of getting the fuel most suitable to given uses. For many years technicians have been attempting to produce a substitute for anthracite from bituminous coal or lignite. The lack of such a substitute on the market today is testimony to the unsuccessfulness of the experiment. Yet, in view of the small reserves of anthracite, the aim was laudable. Technical improvements in bituminous coal-consuming equipment have increased the usefulness of the raw bituminous coal. Coal of subbituminous or lignitic rank has made little or no advance, and it does not seem probable that such coal can gain a position of importance without conversion to a better form. The demand for fuels appears to be headed in the direction of greater preference for compactness and cleanliness—attributes that the extremely low-rank coals do not possess. Consequently, the greatest need for low-rank coal is processes for converting it into a better product, if possible a smokeless fuel. Among the processes, conversion to a liquid fuel has only slight promise.[1] Conversion to gaseous form has some possibility of further development in areas where natural gas is not plentiful. Conversion to a coke or semicoke has distinctly the best prospects and should be a main object of research. It should be stressed that the lack of large commercial development of low-rank coals is a handicap to research work in the field by private concerns. One cannot expect research to develop as rapidly there as it has where commercial possibilities have been demonstrated. Intensive work by public research bodies, therefore, is essential if neglect of low-rank coal use is to be avoided. It remains a fact that consumption tends toward the upper limits of quality, whereas the available reserves increase in quantity in the opposite direction. There is accordingly a continued need for scaling down as much as possible toward the lower ranks.

Technical improvements in coal preparation and processing have already extended the range of coals used, so that some relief from concentration on the highest ranks of coal has been provided. Up to the present time the byproduct coking process has been the chief means for enhancing the usefulness of coals, but the process falls short of providing an outlet for the very low-rank coals, and much of the extension has taken place only by mixing low-rank bituminous coals with high-rank bituminous coals. The by-product method has resulted in revolutionary changes in the coke industry (fig. 23). But it has extended only to a small extent the range of coals which can be used. The old beehive process worked best with coals such as those found in the Connellsville district of western Pennsylvania. The beehive ovens were at the mines, whereas most of the byproduct ovens are now at or near steel mills. In 1893, when the first byproduct ovens were put into operation in this country, at Rochester, New York, 66 percent of the coke output of the country was beehive coke produced in Pennsylvania, largely in the Connellsville district. By 1913 the percentage was down to 56 and by 1937 to only 5. Each year many more beehive ovens are abandoned than are built. No doubt the industry has persisted as long as it has because of the hope of earning something on the capital previously invested. The fact that production in beehive ovens requires less capital and can be varied more readily with demand is also a factor. From this position of extreme concentration the coke industry has spread to many States, the leading ones being Pennsylvania, Ohio, New York, Massachusetts, New Jersey, Maryland, West Virginia, Michigan, Illinois, Indiana, Alabama, and Colorado.[2] Almost as much coal for coking now comes from West Virginia as from Pennsylvania, and other States also contribute large quantities.[3] The extension of the coke industry, however, has been greater geographically than it has been among the ranks of coal. It still remains true, although less so than formerly, that the better ranks of coal are utilized for coke production.

Improvement of Low-Rank Coal

The coke industry, nevertheless, suggests the methods most likely to lead to a wider use of low-rank coal. Production of liquid fuels from coal appears to be further from practicality than that of smokeless solid fuels. Gasification of coal probably will not develop further until reserves of natural gas, and perhaps also of oil, begin to yield less than the demand. The most promising processes for the production of better solid fuels from low-rank coal are as follows:

1. High-temperature carbonization.
2. Low-temperature (and medium-temperature) carbonization.
3. Briquetting after dehydration and preferably after some devolatilization.
4. Pulverization.

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[1] Production of liquid hydrocarbons from coal in the United States is not likely to be able to compete against relatively cheap petroleum products for many years. In Europe it has succeeded only under the stimulus of heavy subsidies and exceedingly high taxes on petroleum products.

[2] Cf. Fritz and Veenstra, *Regional Shifts in the Bituminous Coal Industry*, University of Pittsburgh, Bureau of Business Research Monographs, No. 4, 1935, pp. 116–27; also *Minerals Yearbook, 1938*, p. 786.

[3] See table in *Minerals Yearbook, 1937*, pp. 911–12.

High-temperature carbonization is applied in the typical byproduct coke plant of today. The method produces a coke entirely satisfactory for metallurgical use. The coke may be stored for long periods without appreciable deterioration; it burns with a smokeless flame, but it is somewhat brittle for handling and shipping; it is not considered as desirable as anthracite for residential and other small-scale heating uses; in fact, residential use of coke has not increased since 1933. The result is that high-temperature coke has found limited application outside the iron and steel industry, and production is concentrated on coke required for metallurgical purposes.

The problem of improvement of low-rank coals by carbonization, nevertheless, was given widespread attention both in the United States and in Europe during the decade following the World War. Research work in low-temperature (and medium-temperature) carbonization of low-rank bituminous coals and lignite was pursued diligently.[4] Most of the methods were unsuccessful when applied commercially. One should observe, however, that the exceptionally adverse conditions in the coal industry during the period were not favorable for the introduction of any radically new methods, especially since the chief problem was reduction of mining capacity already existing in fields producing high-rank coal. The absence of a large market for coal tars produced in abundance by the low-temperature processes was a further retarding factor.[5] Given better promotion in areas having mostly low-rank coal, and given an improving market for tars through an expanding chemical industry, together with more emphasis on smoke elimination, low-temperature carbonization may become a large industry. The industry, in fact, has already made a beginning. One small plant at Dickinson, N. Dak., has been producing since 1929 a low-temperature coke from lignite.[6] The world's largest low-temperature coke plant was built at New Brunswick, N. J., in 1929, but it was unable to withstand increasing competition from other fuels after the financial crash of 1929.[7] About the time the New Brunswick plant was having difficulty, the Pittsburgh Coal Co. began operation of a low-temperature plant near Pittsburgh; the plant has been expanded and is still operating. Another low-temperature plant at Moundsville, W. Va., has been producing briquetted fuel from carbonized slack.[8] One of the most encouraging signs is that the capacity of the Dickinson, N. Dak., plant was greatly expanded in 1937. A new concern at Minot, N. Dak., plans to reconstruct its briquetting plant destroyed by fire almost as soon as it was completed.[9] The Pittsburgh Coal Co. plant has had difficulty in keeping up with orders during the heating season.

In recent years, briquetting of coal has been gaining in importance, although output remains small in comparison with total coal production. Briquets are produced mainly from fine coal or coke usually with the aid of a binder consisting of asphaltic pitch, coal-tar pitch, asphalt, aspholeum, starch, or road oil. In this way coal or coke is salvaged that might otherwise have little usefulness. Packaged fuel also is growing, and, of course, better preparation (cleaning, sizing, etc.) of coal results in a more convenient fuel.[10] In Germany an extensive industry has grown in connection with the dehydration and briquetting of brown coals. Sixty-five percent of these coals are briquetted. This process might be carried a step further in its application to American coals so that a nearly smokeless fuel could be produced. Experiments conducted in Illinois seem to indicate the feasibility of forming briquets without a binder after the coal has been dehydrated and partially devolatilized.[11] The cost of production of a ton of smokeless briquets by this method, excluding the cost of the coal, is estimated to be only 50 cents to one dollar.[12] This process, or a similar one, may well

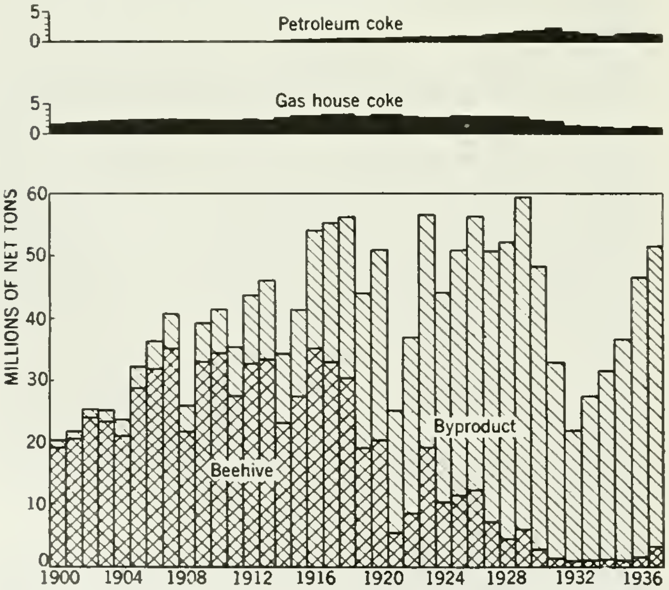

FIGURE 23.—Production of Coke in the United States, by Type, 1900–37. (Reproduced from *Minerals Yearbook, 1938*, p. 782.)

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[4] See, for example, papers delivered at the International Conference on Bituminous Coal, Carnegie Institute of Technology, Pittsburgh, Pa., 1926 and 1928.

[5] Rice, Fieldner, and Tryon, "Conservation of Coal Reserves," *Third World Power Conference*, sec. IV, Paper No. 11, p. 44.

[6] *Minerals Yearbook, 1937*, pp. 949 and 960.

[7] A. C. Fieldner, "Recent Developments in Coal Utilization," *Minerals Yearbook 1932–1933*, pt. III, p. 441.

[8] *Ibid.*; see also Fieldner, "Recent Developments in Coal Preparation and Utilization," *Minerals Yearbook, 1934*, p. 641.

[9] G. S. Goodman, "Fuel Briquets and Packaged Fuel," *Minerals Yearbook, 1938*, p. 799.

[10] Cf. L. N. Plein and J. B. Clark, "Fuel Briquets," *Minerals Yearbook, 1937*, pp. 955–68.

[11] *Minerals Yearbook, 1937*, p. 958.

[12] *Ibid.*

be the answer to the problem of producing from low-rank coal, and the less desirable parts of high-rank coal, a solid fuel that will withstand handling, that may be stored for considerable periods, and that meets the need for cleanliness in firing. A fuel of this type would be a decided aid to conservation of the better ranks of coal.

Improved adaptation of equipment to burn coal in pulverized form may offer a larger outlet for low-rank coal as well as for much fine coal from better beds, not now considered marketable. A large percentage of the anthracite, during the early years of the industry, was left in the mine or thrown on the culm bank for lack of a market. Although a considerable part of this waste has been eliminated, low prices for the small sizes of anthracite still result in wastage. A price at the breaker of only $1.45 for the Buckwheat No. 3 (Barley) size against one of $5.21 for the large stove size—1937 average prices—suggests how little incentive, relatively, there is to conserve the small sizes. A better market for pulverized coal may encourage larger recovery of the fine coal.

With powdered-coal combustion, coal of widely varying properties may be used.[13] Lignite and subbituminous coal as well as anthracite may be burned. Similar significance attaches to stoker-fired installations using coal of small sizes. In fact, the high efficiency obtained from pulverized coal has been equaled by stokers.[14] Combustion of coal in pulverized form affords maximum economy in the case of anthracite culms and low-volatile coals, whereas for lignite the saving is often negligible or perhaps even negative.[15] It is probably more profitable to burn lignite in mechanical stokers.[16] Recent innovations in stokers are solving the technical problems involved in handling coals with various characteristics. The recently developed spreader stoker has a wide range of application.[17] In addition to bringing a wider variety of coals into use, powdered-coal and stoker-fired methods afford high efficiencies and practically smokeless combustion. The chief disadvantages are explosiveness of suspensions of coal dust in the air and the tendency for the ash of such coal to blow out the chimney into the atmosphere. These difficulties need further study.

Coal *vs.* Other Sources of Energy

There is no valid reason for stopping with coal in considering the question of substitution of a more abundant for a less abundant energy. In some sections of the United States, water power, renewable almost without end, is the means for conserving coal resources.

Water power, nevertheless, cannot replace coal in large part. Total power inherent in falling water throughout the country probably is not equal to one-half that in the coal mined currently, and not all the inherent power can be utilized; some of the power generated is not within reach of a market, some of the water is needed for nonpower purposes, and often the power, if available, may be developed only at high cost.

Although the scope of application is limited, water power should be viewed as one means for sharing the burden of energy production. Development of water power heretofore, both privately and publicly, indicates the feasibility of using it as a partial substitute for coal. The argument that water-power use suppresses coal-mining activity and, therefore, that water power should not be developed, even though available at a competitive advantage, is not one supported by the concept of rational utilization of power resources.

On the other hand, the idea of conservation when applied to the relationship of coal to oil and gas is favorable to larger use of coal. All the available evidence indicates a life for oil and gas reserves only a fraction as long as that for coal. New discoveries of oil and gas would have to multiply reserves, known at present, hundreds of times to alter this fact. This difference in reserves presages exhaustion of oil and gas centuries before the coal is gone. Accordingly, further substitution of oil and gas for coal means further reduction of the abbreviated life of oil and gas. There is also the possibility that utilization of oil and gas has already reached proportions not in the best interests of the Nation. If the domestic economy becomes dependent on foreign sources of oil, and if natural gas becomes unavailable, the position of the United States as a world power, being changed from a "have" to a "have not" status in those respects, will suffer. Even if that threat lies decades or even scores of years ahead of us, it cannot be lightly brushed aside.

Balanced Consumption of Fuels

How can a balanced consumption be promoted? Every consideration of the problem runs into the necessity of dealing not with three simple fuels but with three entire classifications or assortments of fuels: not with three simple uses, but with an array of uses, some of them overlapping and some being completely noncompetitive. Greater importance attaches to what specific applications of power will do than to the total bulk of fuel consumed. The reason for preferring a fuel in a given use lies in comparative cost. Into cost enter factors of scarcity and physical adaptation of a fuel to a use. Coal is not used for automobiles, for example, because it is not physically suitable, and the cost of converting it to a suitable liquid form is prohibitive in comparison with the alternative cost of gasoline.

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[13] William Harvey Young, *Sources of Coal and Types of Stokers and Burners Used by Electric Public Utility Power Plants*, The Brookings Institution Pamphlet Series, December 31, 1930, vol. II, No. 2, p. 33.

[14] A. C. Fieldner, "Fuels of Today and Tomorrow," reprint from *Proceedings of the American Society for Testing Materials*, vol. 37, pt. I, 1937, p. 12.

[15] L. K. Ramzin, "Comparative Efficiency of Burning Typical Kinds of Fuel," *Proceedings of the Second International Conference on Bituminous Coal*, vol. I, 1928, Pittsburgh, Pa., pp. 951–52.

[16] *Ibid.*, p. 958.

[17] J. F. Barkley, "The Forced-Draft Spreader Stoker," *Transactions of the American Society of Mechanical Engineers, 1937*, vol. 59, pp. 259–65.

The chief advantage of gas is ease of heat release. In this respect it is almost a perfect fuel. But it has the disadvantage of requiring a large space for the energy contained. It is therefore not applied in mobile equipment.[18] Petroleum fuel products, such as gasoline, kerosene, naphthas, and fuel oils, also rank high in case of heat release, especially when vaporized as in an internal combustion engine, and, in addition, they are compact and easy to transport. A major disadvantage of both gas and petroleum fuel products is the relatively high cost per unit of the energy delivered and, from a long-term point of view, lack of availability for an extended period of time. Coal, on the other hand, is a compact and economical fuel with a reserve supply sufficient, if prudently used, to meet heavy demands for many generations. The solid structure of coal, however, makes it a much less desirable fuel than gas or oil from the standpoint of ease of handling in consuming equipment. For some uses, coal will never replace gas or oil unless it is first converted to a gaseous or liquid form, a transformation that is technically difficult to make and thermally inefficient.[19] There are, therefore, close limits on how much the weak links in the fuel supply may be strengthened by a shift to a more plentiful but wholly different type of fuel.

The various fuels come into rather direct competition with each other in the steam-raising and space-heating uses. There is also much indirect competition, illustrated in the partial displacement of coal-energized street-railway, electric-interurban, and steam-railroad transportation, by automobile, bus, and truck transportation. Technically one fuel may be substituted for another fuel in almost any use. Gas or oil may be made from coal, or, conversely, a solid fuel consisting mostly of carbon may be produced from oil or gas. The effect of technological progress is to make fuels more nearly interchangeable. Practically, however, interchange is inhibited by the high cost of converting the form of the fuel. The economy of direct consumption tends to hold in check the amount of processing, or conversion, applied to the fuel. The bulk of the coal mined today is consumed in solid form and will probably continue to be consumed that way. An analogous condition exists in the oil and gas industries. In accordance with this developed tendency, the limited reserves of oil and gas should be retained for the uses in which coal is relatively much less satisfactory. For similar reasons, a shift from high-rank coal toward low-rank coal needs to be encouraged. Owing to the much more plentiful reserves even of high-rank coal than of oil and gas, however, a small reduction in the life of coal reserves would be compensated by a marked extension of the life of oil and gas reserves. In the course of two or three decades, the nation would gain by fending off the day of increased production of liquid fuel and gas from coal or other energy materials.

Growth of oil and gas consumption by leaps and bounds, coupled with retrogression in the coal industry, these trends later to be reversed to the detriment of oil and gas consumers, can hardly be considered a balanced development of fuel resources. It would be more reasonable to correlate use with availability of the fuels, clearly an end not reached under the current organization of the energy-resources industries.

One should not confuse this condition with that involved in nonwasting assets. Nature has already provided substantially all the oil, gas, and coal that will ever occur. There happens to be more coal in the ground than oil or gas. It would have been better, as far as one can see now, were the reverse true, but the basic facts in the case cannot be changed. The utilization policy has to be oriented to a condition not by any means ideal. Also the real or supposed stake of economic regions and of vested interests becloud the major issue with respect to the objective of conservation. One cannot be oblivious to the fact that millions of dollars are spent each year to achieve a temporary competitive advantage, even though such action may have a serious effect on the life of the fuel assets. Competition and conservation of wasting reserves are antagonistic to the extent that competition looks only to current operations whereas conservation centers on the ultimate outcome of utilization. As long as both competition and conser-

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[18] Some exception must be made for bottled, or liquefied gas.

[19] Some typical heat values (not counting heat lost in utilization) and illustrative cost comparisons are as follows:

Fuel	Cost per unit	Heat value (B. t. u.)	Cost per 1,000,000 B. t. u.
Coal	$5 per ton	13,500 per pound	$0.19
Fuel oil	$0.05 per gallon	145,000 per gallon	0.34
Kerosene	$0.14 per gallon	135,000 per gallon	1.04
Natural gas	$0.50 per thousand cubic feet.	1,075 per cubic foot	0.47
Manufactured gas	$1 per thousand cubic feet.	530 per cubic foot	1.89
Electrical energy	$0.03 per kilowatt-hour	3,410 per kilowatt-hour	8.80

Note especially the high cost of manufactured gas, largely a product of coal. No reliable data are available on the cost of producing liquid fuel from coal, but it is known that the cost is 3 to 6 times as high as for fuel oil. Cf. A. C. Fieldner, "Fuels of Today and Tomorrow," Reprint from *Proceedings of American Society for Testing Materials*, vol. 37, pt. I, 1937, p. 21.

vation are retained as objectives, concessions must be made on both sides.

What, then, are the issues involved in utilization of coal against that of oil and gas? In the first place, one must decide the purposes for which the fuels are to be reserved. The least dispensable uses of gas are for domestic cooking and water heating, for delicately controlled industrial heating processes, and perhaps for supplementary house heating, whereas the least dispensable uses of petroleum are for the production of lubricants and of fuels, principally gasoline, to be used in mobile internal-combustion engines. Coal, as a rule, remains the cheapest source of fuel energy for large volume steam-raising and space-heating requirements. But there is no doubt that it is more difficult to handle in consuming equipment than liquid or gaseous fuel. The ash content and dirtiness of coal and the difficulty of obtaining quick and accurate responses in combustion are objectionable features for certain uses. Blame for smoky atmospheres in cities also rests squarely on coal. Consumer preference is no doubt overwhelmingly in favor of a cleaner fuel and a greater precision in heat control than are usually provided by coal. These facts should not be disregarded in any consideration of increased consumption of coal in the place of oil and gas. Primary emphasis should be placed on research to promote the use of coal by overcoming these objections of consumers to coal. When methods are perfected for obtaining heat from coal about as automatically and with about as much cleanliness as from oil or gas, coal, as a low-cost source of energy, will regain much of the position it has lost since the advent of oil and gas. It is to be hoped that the coal industry will realize to an increasing extent the importance of technical research to produce a better fuel and better equipment for coal utilization. Research by governmental agencies directed to the same objectives, especially with respect to the relatively neglected low-rank coals, should be fostered more than it has been in the past. A. C. Fieldner says with respect to estimates cited that, although 10 to 12 million dollars are spent annually on research and development in the refining of petroleum, that more should be expended on the preparation and direct utilization of coal.[20]

A lag in coal research is unfortunate from a conservation point of view. Such a lag accelerates the declining trend in coal production, a trend that will have to be reversed all the more sharply when oil and gas reserves begin to dwindle under the strain of overexpanded consumption.

Interest in coal research, nevertheless, has increased since the World War. The United States Bureau of Mines has made significant contributions, not only through its research but also in disseminating detailed information about research work being done elsewhere in coal. The State of North Dakota has been attempting to improve the usefulness of its lignite deposits. Most of the large coal-producing States, and many others as well, have done research work on coal either through State departments or through State universities. Research has been pursued also by private organizations, such as the Coal Research Laboratory of the Carnegie Institute of Technology, fellowships at Mellon Institute, Anthracite Industries, Inc., the research laboratory of the Anthracite Institute, and Bituminous Coal Research, Inc., at the Battelle Memorial Institute. Much of the research has been indirectly beneficial to the coal industry by finding new uses, and therefore new markets, for coal byproducts. A direct result, however, has been the perfection of small stokers to provide automatic firing of coal with almost no emission of smoke. These stokers have gained wide acceptance; sales for domestic use have increased, according to the United States Bureau of the Census, from 7,000 in 1932 to 93,500 in 1937, a gain far greater than that for oil burners. Total sales of mechanical coal stokers increased 22 percent from 1936 to 1937, whereas sales of oil burners decreased 3 percent. The monthly figures for 1938 show a continuation of the shift from oil burners to coal stokers. Although this shift favoring increased coal utilization is taking place after much of the expansion of oil consumption has already occurred, it represents a change toward a more balanced use of fuel reserves. It has the feature considered of prime importance, the gaining of consumer preference by making coal a more serviceable fuel.

Despite these favorable signs, the introduction of this equipment is not occurring with sufficient rapidity to accomplish much toward distributing the use of fuels more nearly in line with the backlog of reserve supply. The trend of consumption has already gone far in the direction of rapid depletion of liquid and gaseous fuel reserves. Under this condition, minor correctives have the effect only of locking the stable after the horse is out. In view of the decisive difference in magnitude between oil and gas reserves and those of coal, some positive intervention seems not merely justified but essential to avoidance of early exhaustion of oil and gas. Any overt intervention, however, should be considered supplementary to improvement of methods of coal use and not a substitute for them.

Interfuel Policy

Differences of opinion on how far enforced reservation should go will be found even among those who favor in principle conservation of relatively scarce fuel resources by the substitution of more plentiful fuel resources. No fixed rules can be set down to act as a guide. Owing to the uncertain course of technological progress in fuel production and utilization, as well as the uncertainties as regards total reserves, especially of oil and gas, eventually to be discovered, measures adopted should be carefully considered. A further fact is that hardships caused by too strict control may be as objectionable as those arising from errors of exploitation.

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[20] Fieldner, "Fuels of Today and Tomorrow," *op. cit.*, p. 22.

Behind interfuel competition is a difference in cost relationships determining what fuel can win a certain fuel market. The bulk of the costs in the coal industry are labor costs which vary about in proportion to output. Labor outlays alone constitute more than 60 percent of the total costs of mining. Ability to continue mining operations depends on obtaining a market price for the bulk of the output sufficiently high to cover these out-of-pocket outlays. Consequently, the range of variation in prices of coal at a given time is comparatively small. Only the price of those portions, such as slack, or fine coal, considered to be a surplus necessary to yield the main product, may be cut to a dump-level basis. Cost relationships are much different in the oil and gas industries: Once the wells are drilled and the pipe lines and refineries are built, only a small fraction of the cost then depends on output.[21] Indeed, as has been true in the Texas Panhandle, gas producers may be faced with the choice between selling gas at almost nothing and blowing it into the air. A similar situation exists after investment has been made in pipe lines or refineries. The existence of a general surplus, or off-peak periods of utilization, or the production of an incidental product, or byproduct, encourages stratification of the price structure. Although oil and gas are normally high-priced fuels, the price is cut, in many instances, sufficiently to make an unbeatable bid for markets formerly supplied by the coal industry. Fuel oils, produced in abundance, and usually competing directly with coal, are commonly sold for less than crude oil, if transportation costs be allocated on a unit basis. In other words, assuming that the industry has an income equal to outgo, more than a proportionate share of the overhead costs are allocated to products other than fuel oil. Similarly, many of the sales of natural gas are made at prices below the average cost of transportation, even though the gas sold is substantially a uniform product. It has been estimated that the average cost of main-line transportation, including a moderate return on investment, is 3 to 4 cents per 1,000 cubic feet of gas per 100 miles.[22] On this basis, natural gas consumed in Illinois, most of which comes from Louisiana, the Panhandle of Texas, or southwestern Kansas, would require an average outlay for transportation of at least 16 to 24 cents, yet the average price to industrial consumers in 1936 was only 18.4 cents.[23] A similar relationship exists for Indiana and possibly Michigan, focal states in eastern coal competition. Part of the industrial sales of gas are made at extremely low rates to so-called "main-line industrial" consumers.[24] To the extent that these low rates induce consumption of gas for needs that could be met equally well by the more abundant coal, the sales of such gas are for inferior use. Rapid exhaustion of relatively scarce fuel resources by turning them into low-grade use is injurious to the long-term interests of the higher levels of consumption. Hence, directive control to relate consumption to volume of reserves is needed to achieve a balance that unrestricted competitive development fails to accomplish.

Avenues feasible for such control are two in number: (1) price regulation, and (2) taxation. It is not usually considered within the province of democratic government to dictate to consumers what they shall or shall not consume. Prohibition of certain kinds of fuel consumption should be a measure of last resort. Although such measures are often used abroad, the condition of fuel resources in United States has not reached the point of making such desperate steps necessary. Milder means seem adequate to the task of conserving the resources to their most beneficial uses. In general, efforts should be directed to a mere modification of conditions to be met before consumption is permitted, and not to an actual veto of consumption, the central idea being that attitudes should be altered to conform to the needs of balanced utilization.

The Federal Government has already undertaken to regulate prices of coal, and it regulates rates charged by interstate carriers of fuels. Its regulation of coal prices will not promote larger consumption of coal. "Fair prices" worked out under the act will undoubtedly be somewhat higher than those the industry has been able to maintain without regulation. Higher prices for coal encourage the use of oil and gas. Regulation of pipe-line rates has probably had a minor effect on the delivered price of oil and gas, although it has tended to reduce discrimination among shippers and areas. Government ownership of pipe lines would enlarge the sphere of Governmental control, but it would also transfer to the Government the business problems of the industry. At best it would be a backhanded approach to the problem of conservation.

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[21] Water power involves a similar cost relationship because the cost of the dam is the principal item. Unless the flow of water can be regulated to meet variations in demand, off-peak demand should be encouraged to prevent wastage of power.

[22] Judson C. Dickerman, "Organization of the Production, Transportation, and Distribution of Natural and Manufactured Gas in the United States of America." *Third World Power Conference*, Section II, Paper No. 6, Washington, D. C., 1936, p. 7.

[23] *Minerals Yearbook, 1938*, pp. 30 and 939–42.

[24] Cf. *Brief on Behalf of Legislation Imposing an Excise Tax on Natural Gas*, submitted to the Division of Economic Research and Planning of the N. R. A. by the National Coal Association and the United Mine Workers of America, March 13, 1934, Washington, D. C. Table IV, p. 59, gives a compilation of data published by the American Gas Association.

It should be observed that the type of rate charged for transportation service affects markedly the scale of prices for the delivered product. A flat charge for the use of pipe-line facilities will encourage price cutting for off-peak loads, and therefore it will increase low-grade use of the resources. On the other hand, a metered rate, for example, 15 cents per thousand cubic feet of gas transported, places a floor below which prices cannot be cut. Although such a rate may raise the average cost of the delivered product, it would be favorable to conservation. The question arises whether conservation is worth the price. Considering the absolute dependence of our civilization on energy resources, the answer is clear.

Railroad freight rates are already on a "metered" basis. Since the bulk of the coal mined is transported by rail, the delivered price of coal has a minimum set by the per-ton freight charge. Price cutting at the point of consumption is thus restricted to a plane above this unit charge. Natural gas, being transported by pipe lines, is in a wholly different category. In 1937, 62 percent of the marketed natural gas production of the country was in Oklahoma, Texas, and Louisiana. Part of the gas produced is consumed in gas fields or in nearby urban centers. Regulation of pipe-line rates for the portions of the gas not transported to distant points would have little effect on consumer prices. Long-distance transportation of natural gas, however, is gaining rapidly. In 1927, gas was not piped from any producing State beyond a contiguous State. At the present time, gas from wells in Texas is piped into Michigan. More than one-fourth of the natural gas produced in 1936 entered interstate commerce. The proportion probably increased in 1937 and 1938. If gas consumed in or near the producing fields, for the manufacture of carbon black, for drilling, for pumping, or for operating gasoline recovery plants, were excluded from the count, the proportion of interstate commerce would have been close to one-half. Since Federal regulation is applicable to this commerce, the rate schedules previously suggested could be arranged to promote reservation of the supply to a greater extent for high-grade uses.

The levy of an excise tax on gas would have more far-reaching effects than regulation of gas transportation. One may cite in favor of a uniform tax levy per unit of consumption that it would have less proportionate effect on high-priced gas than on low-priced gas. To illustrate the point: a tax of 10 cents per thousand cubic feet would double the price of gas previously selling at 10 cents, whereas it would increase 70-cent gas only one-seventh, assuming, of course, that the tax is passed to consumers. A general penalty tax might be less harmful than the penalty unavoidably exacted when gas reserves begin to wane. Whereas rates for natural gas with a heat value of 1,075 B. t. u. per cubic foot commonly run 45 cents to 60 cents per thousand cubic feet even for small-scale users, those for manufactured gas of about 530 B. t. u. typically average more than one dollar per thousand cubic feet. From this comparison it is seen that manufactured gas commonly costs four times as much as natural gas for equivalent heat value, an increase far greater than an effective tax would impose. A general tax, nevertheless, should be avoided until other measures of control prove to be inadequate for the task of conservation.

A selective tax on gas, such as one for designated uses, could control consumption almost at will. The real need, however, is not for intricately regimented consumption such as that instituted under dictatorships but rather for reasonable prudence in utilization. A tax on sales below a certain price would be far less drastic and would tend to eliminate low-grade uses while at the same time leaving a considerable measure of discretion to consumers. Gas not sold, of course, would escape taxation. On the other hand, the plan would lead to the problem of avoiding multiple taxation of repeat sales of gas. The effects would be similar to those of metered rates for transportation of gas. But, owing to the application of the tax to much intrastate commerce as well as to substantially all interstate commerce, it would be a step ahead of regulation of interstate carriers.

Again, it should not be assumed that a uniform penalty would achieve uniform results with regard to conservation. For some consumers, the desired objective of turning them to utilization of the more abundant coal reserves would be accomplished with only small increases in the price of gas. Other consumers either would have to absorb price increases, however large, or discontinue consumption of fuel. The effects of price manipulation are thus very unevenly distributed. Because most of the States producing natural gas are not large producers of coal, intrastate competition between coal and gas is relatively less severe than that in interstate shipments. Control through regulation of interstate commerce therefore may go a long way toward rationalizing demand.

A similar problem appears in connection with pipeline shipments of oil eastward from the western producing fields. Undoubtedly the largest market for oil is in the populous section of the country east of the Mississippi River and north of the Ohio and Potomac Rivers, the section that is by far the largest consumer of coal. But about nine-tenths of the crude petroleum is produced west of the Mississippi River. Control of the enormous flow of oil from the midcontinent producing fields northeastward to consuming States along the lines described for natural gas could be a weighty factor in conservation.

Unlike natural gas, however, substantial quantities of oil are brought by tank ships from the Gulf Coast fields and from foreign countries to the Middle and North Atlantic States. Of the various petroleum products, except petroleum coke, fuel oil is in the most direct competition with coal. The possibilities of automatic oil heating of homes did not attract market attention until 1918, and sales of oil for domestic heating did not grow rapidly until 1923.[25] That consumption of oil for heating has continued to grow in recent years is indicated by the increase in sales of heating and range oils from 77 million barrels in 1934 to 127 million barrels in 1936.[26] In the latter year, 56 percent of the sales were in the six New England and Middle Atlantic States, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, and Pennsylvania.[27] Two States, New York and Massachusetts, took more than a third of the national total. These States lie in the heart of the anthracite market. Although anthracite reserves are not nearly so plentiful as bituminous coal reserves, they are many times as large in relation to demand as are the reserves of petroleum. No doubt the downward trend of anthracite production can be traced in large part to the growth of fuel oil consumption within the anthracite market area. If only the question of conservation be considered, this growth is objectionable on the score that it means accelerated depletion of a fuel reserve already well on the road to exhaustion. There does not seem to be much that can be done through voluntary cooperation to bring about a reversal of this trend. Any action now taken will have the handicap of an extremely late start. Dispensing of fuel oil is a major business, and, in addition, millions of dollars have been invested by consumers in oil-burning equipment. These developments cannot be undone innocuously by intervention; but the question remains whether continued expansion of fuel oil consumption should be permitted, only to be choked off along with other more necessitous uses by eventual failure of reserves. A wise conservation policy would reserve petroleum "for those special automotive needs that can be served best by a liquid fuel * * *"[28] Coal stokers can now provide automatic control of firing with either anthracite or bituminous coal. The old argument for the use of oil to give automatic control has lost much of its force. Coal stokers are coming into use rapidly. They probably will not be adopted on a wide enough scale, however, immediately to reverse the trend toward fuel oil. Total sales of stokers were 101,800 in 1937, whereas sales of oil burners were almost twice as large.

Regulation of fuel-oil prices would be a difficult undertaking owing to the consumption of fuel oil in refinery cracking plants, as well as in space heating. The use of fuel oil for the highly efficient Diesel motors further complicates the problem. Likewise a gallonage tax on fuel oil for space heating and steam production in power plants, such as has been proposed in the legislature of Pennsylvania, would not be a simple solution. Such a tax probably would arouse opposition in all but the coal-mining areas, even though it might be a boon to the long-term interests of motorists. The temptation to let matters run as they will and to rebuild fences after they are broken is probably too strong to be overcome. A courageous program for conservation, nevertheless, should include some means for retardation of this wasteful use of oil. A tax high enough gradually to discourage the directing of fuel oil into such use would be preferable to inaction.

Numerous persons in the coal industry have advocated a higher tariff on imported oil, especially to prevent encroachment of fuel oil into the heating market. The rate of one-half cent per gallon, it is asserted, should be raised to three cents per gallon. This type of tax might help to conserve foreign resources of oil. It probably would do so at the expense of domestic resources. Although it may be in point to consider what foreign sources of oil will be tapped when the domestic supply fails, the immediate need is for domestic conservation. Consequently, if nothing is done at home to prolong the life of the reserves, it would be an error to give an added advantage of extended life to foreign fields. The tariff canopy, so often raised, might provide a little shelter to the coal industry, but it would be a backward step insofar as conservation is concerned.

Let it be repeated that conservation of the Nation's relatively scarce fuel resources, oil and gas, needs to proceed as far as possible through improving the usefulness and therefore the bargaining power of the more abundant coal resources. Direct intervention by governmental bodies is not a panacea for conservation or for the poor operating position of the coal industry. The more accomplishment along technological lines to correct the maladjustment between utilization and reserve supply, the fewer the headaches to be expected from governmental intervention. Indeed, it is probable that much action now considered essential may be quite unnecessary after technology has been directed to serve the interests of conservation.

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[25] See the data in E. B. Swanson, *National Survey of Fuel Oil Distribution, 1929*, U. S. Bureau of Mines (printed by American Petroleum Institute, November 1930), p. 19.

[26] U. S. Bureau of Mines, *Statistical and Economic Surveys*, Petroleum Economics Division, Mineral Markets Reports, No. M. M. S. 600, October 26, 1937 (mimeographed).

[27] *Ibid.*

[28] Rice, Fieldner, and Tryon, *op. cit.*, p. 48.

It is recognized that only the critical points in the problem of balanced utilization of fuels have been discussed. A thorough program of conservation designed to preserve diversity in the Nation's energy resources for many generations probably would have to go beyond the suggestions made. Plans, of course, must be developed on the basis of current knowledge, but unforeseen developments in the future, such as additional discoveries of oil and gas and innovations in fuel utilization, tending to overcome the handicaps of exhaustion of portions of the fuel supply, may justify a measure of caution in the scope of the conservation program. Unless the critical phases are attacked, other controls cannot have much chance of success. The ideal apportionment of fuel reserves among the channels of consumption would be one that maintains a slight upward inclination in the long-term trend of coal consumption in the interim that oil and gas—both showing marked upward trends at the present time—are produced in quantities adequate to meet market demands. In this way an easier transition may be effected when exhaustion begins to take toll through higher prices for oil and gas or through enforced shifts to coal for uses in which liquid or gaseous fuels are advantageous.

Losses in Coal Mining and Handling

In the mining and handling of coal, a portion is left in the mine, thrown on the refuse pile, or scattered around where it becomes unavailable. Coal abandoned underground during mining is usually lost forever. Buckles, cave-ins, and inflows of water generally render the remaining coal inaccessible or minable only at great risk and expense. The low value of coal per unit of bulk is unfavorable to reworking of mines, although the tendency is not uniform. Since coal varies in price according to quality and location, a difference in inducement exists among various mines. Naturally, there is less incentive to go back for low-rank coal than for high-rank coal. Although bituminous coal mines are rarely reopened—some exceptions occur around large urban centers—after initial mining operations are completed, anthracite mines are sometimes reopened for further mining. One anthracite mine in which mining was "completed" 40 years ago has produced more coal since its operation was resumed than it did before.[29] More than half the coal, however, was left in the mine when the initial operations were terminated. With more efficient mining methods being used today, less coal remains as an inducement for mining old workings. Consequently, elimination of loss requires thorough working of the mine before it is abandoned as a completed job.[30]

Under current methods, coal-mining operations leave millions of tons of coal in the ground in a condition that makes future recovery unlikely even at marked increases in prices. Elimination of this loss leads into numerous practical problems concerning the mining and handling of the coal. These problems are discussed in detail in part III, section I, written by George H. Ashley, State geologist of Pennsylvania, whose long experience with the coal industry has enabled him not only to gain an intimate knowledge of the causes of loss but also to gauge trends and to evaluate remedies. Since physical loss of coal resources is a part of the conservation question quite as much as the determination of what fuel resource is to be used as the Nation's energy source and how efficiently it will be consumed, coal losses are considered in this chapter with respect to the general program of coal conservation. Attention is drawn especially to the extent of the losses and to the advantages to be derived from loss elimination.

Coal losses were investigated by the United States Coal Commission,[31] created in September 1922, as a result of the post-war plight of the coal industry. This Commission, popularly called the Hammond Commission in honor of its chairman, John Hays Hammond, assigned engineers to the task of studying losses under actual operating conditions. There were 71 bituminous coal mining districts in 10 States east of the Mississippi River—the bulk of the production being in those States—included in the survey made in 1923. Field examinations were made of 331 mines, and data were collected in addition from 1,049 mines.[32] Mines represented in the report accounted for 30 percent of the total production in 1921 in Pennsylvania, 20 percent in West Virginia, 15 percent in Ohio (the smallest percentage for any State), 55 percent in Illinois, and 80 percent in Virginia. Data having perhaps a better average coverage were gathered for the Pennsylvania anthracite industry.[33]

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[29] Henry Mace Payne, "The Coal Industry," in J. G. Glover and W. B. Cornell, *The Development of American Industries* (N. Y., Prentice-Hall, Inc., 1932), p. 338.

[30] Mines abandoned before completion, of course, are in a different category.

[31] Not to be confused with the National Bituminous Coal Commission created in 1937 to regulate the bituminous coal industry.

[32] *Report of the United States Coal Commission*, Washington, 1925, p. 1848.

The investigators found six principal reasons for losses in the bituminous coal industry, reasons which apply in a general way also to the anthracite industry. They are as follows, in approximate order of importance:

1. *Coal lost in room, entry, and panel pillars left in the mine.*—This loss ran as high as 45 percent of the reserves worked in one district, and it usually amounted to 10 percent or more. In strip-mining areas, of course, the loss was eliminated.

2. *Coal lost in preparation and handling—underground and surface.*—This loss was an appreciable item in all the districts examined. It was usually about 4 or 5 percent of the reserves worked. No doubt, most of this loss resulted from inefficient methods or from carelessness in handling; and, therefore, it should be classified as avoidable loss.

3. *Coal lost because of thin or dirty beds rolls in the coal-bearing strata, or the existence of overlying streams.*—Some coal was in beds below the minimum required thickness for mining, or excessive dirt in the bed made it unprofitable to mine. Rolls, or "bulges," in the beds interfered at times. Often it was necessary to leave coal under streams to prevent an inflow of water. Although losses from these causes were 10 to 16 percent for about one-tenth of the mining districts, in a majority of the districts they were only 2 to 4 percent.

4. *Coal left on the roof and bottom.*—Maryland, Pennsylvania, and West Virginia mining districts showed higher losses from this cause than did most of the districts in other states; the average loss for all areas was slightly less than 3 percent. In some areas, where the roof structure above the coal was too soft to be supported safely by timbering, the loss was unavoidable. Sometimes, also, the top or bottom coal was below the required standard of quality. It frequently happens that, as in mines near Clarion, Pa., 1 or 2 inches of coal are left on the floor to prevent the track from sinking into the soft clay underfoot, or the clay bed on the floor covers a thin coal bed, as it does in the Coal Creek district of Tennessee; but recovery of the underlying band is too expensive to undertake. This loss was considered unavoidable by the Coal Commission engineers, although long-term interests might well be served by mining more of the coal lost this way.

5. *Coal lost in boundary pillars and under buildings, railroads, and other surface structures.*—Most of the states have laws requiring boundary pillars to be left between mining properties to prevent flooding of adjoining mines and to prevent conflicts over ventilation, roof support, and trespass. Probably half the loss at boundaries could be avoided by more careful mining. Consolidation of properties and unification of development could, of course, reduce the loss to a negligible figure. Losses under surface structures could be avoided by packing the workings after the coal has been taken out, a usual practice in European mines, but considered costly and therefore difficult to encourage in the United States, where coal resources are more extensive and wage rates are higher.

Losses in these boundary and surface supporting pillars ranged from one to two percent for most of the bituminous coal-mining districts examined. In some populous districts, coal left under urban centers, such as the Pittsburgh metropolitan area, constitutes a considerable tonnage. This coal evidently was not counted into the losses, and if left intact it may be mined effectively by the use of stowing methods in a future period of high coal prices.

6. *Coal lost in oil-well and gas-well pillars.*—Coal left to protect oil and gas wells driven through the coal bed is a very small proportion of the total and occurs only in a few areas, such as northern West Virginia, western Pennsylvania, and eastern Ohio. States often require these pillars as a protection against fire or explosion from oil or gas seepage. Wherever an excessive number of wells has been drilled, a needless waste of coal is one of the results. In West Virginia, however, many of the wells have been abandoned; operators remove the coal up to the wells and plug them beneath the mine rather than leave a pillar of coal standing.

In addition to the losses already considered, large tonnages are lost in overlying coal beds by mining coal in beds below; but, since it is difficult to determine how much coal is rendered unminable in this way, no estimates of the extent of the loss have been provided. Undermining of an overlying bed is not always disastrous to it. The Sewickley bed in the Fairmont district of West Virginia lies 100 feet above the Pittsburgh bed; and, even though the latter has been mined in many areas, the upper bed has not been affected and may be recovered without difficulty. On the other hand, it is often true, particularly when beds are close together, that mining of the lower bed will cause the upper bed to crack or crumple so much that mining becomes impossible or at least hazardous and costly. Extensive destruction of beds by mining of underlying coal has occurred in northern West Virginia, the Clearfield and Somerset districts of Pennsylvania, the Belmont district of Ohio, and in western Kentucky.

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[33] *Ibid.*, pt. II, p. 655. Also Dever C. Ashmead, *Anthracite Losses and Reserves in Pennsylvania*, Pennsylvania Topographic and Geologic Survey, Bulletin M–8, 1926.

Where successive beds are close together, they may sometimes be worked as a unit. Ashley states in part three, section I of this report that in England beds down to eight inches thick are mined in conjunction with other beds. At a strip mine near Huntsville, Mo., a 14-inch and a 48-inch bed are mined together. The interval between the beds averages 20 feet. Systematic mining of two or more beds may often prevent the loss of a valuable bed. In many instances, of course, there is no remedy except to delay mining of the lower beds until the coal above has been taken.

In perspective, one may observe that of the six types of measurable mining losses, those in room, entry, and panel pillars are by far the largest. Such losses accounted for one-half to three-fourths of the recorded total, and, of this proportion, more than half usually was avoidable loss. Chief blame for waste in mining, therefore, rests with the method by which pillars of coal are left to support the mine roof. Technically nearly all this loss can be avoided, as it is in Great Britain and in most of the mines of continental Europe.

Extent of Losses

Aggregate measurable bituminous coal losses in 1923 were estimated at 34.7 percent of the resources of marketable coal being worked.[34] Stated differently, about one-half ton was lost for each ton produced. Among the 10 States covered, losses ran as low as 20 percent, the average loss in Virginia, and as high as 49 percent, the average loss in Illinois (table 5). Production of bituminous coal in 1921, a depression year, was 369 million net tons, and losses were estimated by the Coal Commission (using the 1923 ratio) to have been 196 million net tons. This loss would meet the annual consumption requirements of at least 34 States outside the heavy coal-consuming section in the northeast.[35] Losses of Pennsylvania anthracite, determined for 1921, were 38.9 percent of the resources in the beds worked—34.6 percent was lost in mining and 4.3 percent in preparation.[36] In the southern field of the anthracite region, where the beds are markedly folded and faulted, the loss was 51.0 percent; that is, more coal was lost than was recovered; but in the more easily mined beds of the eastern middle field the loss was 30.6 percent (table 6).

Evidence for earlier years, although less complete than that for 1923, indicates higher ratios of loss. In 1850, 64 percent of the bituminous coal and 75 percent of the anthracite is believed to have been lost in the process of mining. The loss ratios, in 1880, were 50 percent for bituminous coal and 60 percent for anthracite, a level considerably above the 1923 ratios. Unfortunately, no data on losses are available for the years between 1880 and 1923, and no data suitable for comparisons are available for subsequent years. The general opinion among authorities is that losses are about the same as they were at the time of the Coal Commission study; they may have increased. F. G. Tryon gives as his impression, for example, that coal recovery did not improve from 1929 to 1934, and that, on the whole, waste is greater than it was previously.[37] Depressed conditions in the coal industry in the post-war period have not been conducive to more thorough mining. In fact, the uncertainties of the industry have encouraged a wasteful, opportunistic skimming without much thought for the future. Then, too, the introduction of numerous cumbersome machines, such as the types of cutting machines that leave slabs of coal on the floor of the mine, or those that are too cumbersome to be moved into thin or irregular portions of the bed,

TABLE 5.—*Proportion of avoidable and unavoidable loss in bituminous coal mines in 10 States investigated in 1923*

State	Loss in percentage of original coal content		
	Avoidable	Unavoidable	Total
Alabama	18.0	14.9	32.9
Illinois	29.7	19.3	49.0
Indiana	26.7	15.5	42.2
Kentucky	11.8	18.9	30.7
Maryland	12.7	18.0	30.7
Ohio	26.0	14.0	40.0
Pennsylvania	15.5	13.1	28.6
Tennessee	13.2	11.5	24.7
Virginia	5.0	15.0	20.0
West Virginia	10.5	12.3	22.8
Average	19.4	15.3	34.7

Source: *Report of the United States Coal Commission, 1925*, pt. III, p. 1857.

TABLE 6.—*Proportion of loss in mining and preparation of Pennsylvania anthracite, by fields, 1921*

Field	Loss in percentage of original coal content		
	In mining	In preparation	Total
Northern	29.3	3.7	33.0
Eastern Middle	26.3	4.3	30.6
Western Middle	36.0	5.9	41.9
Southern	46.2	4.8	51.0
All fields	34.6	4.3	38.9

Source: *Report of the United States Coal Commission, 1925*, pt. II, p. 655.

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[34] *Report of the United States Coal Commission, 1925*, p. 1857.

[35] Cf. Fritz and Veenstra, *op. cit.*, chs. 4 and 8.

[36] *Report of the United States Coal Commission, 1925*, p. 655.

[37] Testimony in the *Carter Coal* case, Supreme Court of the United States, October Term, No. 636, *Transcript of Record*, vol. I, p. 324. See also James D. Sisler, "Economic Aspects of Bituminous Coal Losses in Ohio, Pennsylvania, and West Virginia," *Transactions, American Institute of Mining and Metallurgical Engineers, Coal Division, 1931*, pp. 196–202.

have not aided, and may actually have hindered, reduction of losses. Very likely, loss of approximately one-half ton for each ton of either bituminous coal or anthracite produced is typical of current mining practice.

Under the best conceivable mining methods, some loss, perhaps 5 percent or less, would be inevitable, but such high recovery would probably be impracticable. Only the losses reasonably avoidable constitute actual waste of coal. Engineers working for the Coal Commission in 1923 came to the conclusion that bituminous coal losses could be reduced from 34.7 percent of the content of the workings to 15.3 percent and anthracite losses from 38.9 to 30 percent.[38] Avoidable losses (waste) of bituminous coal were estimated at 19.4 percent. In the anthracite fields, a much smaller proportion of the actual loss was avoidable, owing to the marked irregularity of the beds and the greater difficulty of recovery. An examination of what was included as unavoidable loss suggests that the estimates were conservative; that is, conservation methods might easily reduce losses to less than the percentages specified as the goal for the future. Extreme precautions, of course, are not likely to be taken until the Nation is driven to them by necessity. Thus in western Europe, where the provision of energy plays a larger part in the economic struggle, losses usually are only 5 to 10 percent,[39] or only about one-sixth to one-third as great relatively as in the United States. Nevertheless, one must recognize, as a practical consideration, the good fortune of the United States in having enormous reserves of coal. Losses of about 15 percent for bituminous coal mines and of about twice that much for anthracite mines, therefore, may be termed a destruction requisite for expeditious mining of the coal in large volume at low cost.

Prevention of Losses

An attack on the problem of waste in mining should direct major attention to the system of mining whereby pillars of coal are left standing in the mine. Waste from this source exceeds that from all other sources combined. Areas with the highest avoidable losses are usually those with the largest losses in pillars.

The room-and-pillar method of mining predominates in the United States. There are numerous variations of the method, but they have in common mining of the coal along comparatively narrow faces, or walls, with pillars, and often entire panels, of coal being left at intervals to support the roof of the mine. Under the more wasteful practices, the pillars and panels are never removed.

Pillar recovery presents a difficult problem in some areas because of damage to surface structures or farm land from surface subsidence. Mining companies are often confronted with excessive claims for damage, and, rather than incur this risk, they prefer to leave supporting pillars of coal. Subsidence, of course, is a serious problem, particularly in rich agricultural States such as Illinois, where land may be rendered almost worthless in a short time by subsidence. The special circumstances of each area should be studied with a view to developing methods suitable to the conditions existing. Packing of the mine cavity to support the overburden of rock and dirt is usually an effective solution. Hydraulic stowing, pneumatic stowing, and hand packing are employed extensively in Germany, but with the best of care subsidence of 5 percent of the thickness of the workings usually occurs, and, with hand packing of rock and refuse, subsidence is usually 50 to 60 percent.[40] Packing of mines does not appear to have possibilities of wide application in the United States. The cost is high with respect to the prices obtained for coal. Nevertheless, systematic study may reveal methods that may be applied. It must be recognized, for example, that methods of pipe-line transportation have been improved markedly in recent years, and it might now be possible to pipe surface refuse back into the mine, thereby obliterating unsightly culm banks from the landscape, and, at the same time, the savings from elimination of haulage to the banks may be applied toward the cost of packing the mine. In other instances, particularly where a thick bed provides a large return per unit of area, the surface land may be restored to substantially its former condition by leveling or grading. Some engineers are of the opinion that it is possible to keep subsidence uniformly distributed so that not much damage is done and not much leveling is necessary.[41] Often, however, the only alternatives appear to be (1) to leave the coal unmined in areas of serious damage from subsidence until higher coal prices warrant the packing of the mines, (2) to leave coal pillars standing to support the overburden, or (3) to allow the surface to fall and introduce systematic afforestation or plant grasses suitable for the prevention of erosion. Wherever the surface land is of little value, not much harm will result from uneven sinking after the coal underground is removed. Some land in moderately flat areas may return to a stable condition if care is taken to prevent gullies from starting. Thus, there are numerous approaches to the problem, and, although rigid rules might be laid down to ensure preservation of the resources, cooperative action directed to the same end appears preferable in order that an undue burden of cost will not be imposed. No great advantages are to be gained by making conservation measures unduly restrictive. A real need exists, nevertheless, for beginning work on the development of a reasonable and effective conservation policy.

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[38] *Report of the United States Coal Commission, 1925*, p. 1886.

[39] National Resources Board, *Report, December 1, 1934*, pt. IV, "Report of the Planning Committee for Mineral Policy," p. 401.

[40] Rice, Fieldner, and Tryon, *op. cit.*, p. 24.

[41] *Report of the United States Coal Commission, 1925*, p. 190.

The room-and-pillar method of mining is the cheapest and usually the best adapted for working coal beds in the United States, but it does encourage waste by affording a temptation to let pillars stand wherever their removal will increase the average cost of mining. Inherently, longwall mining gives a higher recovery because, by the nature of the system, all the coal is taken from a long face, or wall, as operations proceed. The roof may be allowed to drop behind the operations or it may be supported by building pack walls or ribs. The coal may be taken on the advance toward the outer boundaries of the property or on the retreat toward the mine shaft after radial entryways have been driven to provide a means of communication. The longwall advancing system is used in northern Illinois, where a surprisingly high percentage of recovery has been obtained.[42] Total loss may be as low as 5 percent, and most of it occurs in handling and preparation.[43] Yet the average recovery in Illinois is only about 50 percent, and, in two districts, 53 percent of the coal is lost.[44] The low average recovery is due mainly to the application of the room-and-pillar method in all but the two small northern districts, most of the pillars being left to prevent surface subsidence. For average American mining conditions, the longwall retreating system is probably the most practicable of any developed to secure maximum recovery of coal.[45] Theoretically, losses under long wall retreating should be no greater than those under longwall advancing, these losses being about 5 percent, but without careful handling there is more chance that stubs and irregularities may be left behind.

During the post-war period, strip (open-pit) mining has increased rapidly. The proportion of bituminous coal produced by stripping operations rose from 1.2 percent in 1919 to 6.4 percent in 1936. Introduction of larger and more mobile shovels has increased the depth to which strip mining may profitably go.[46] The effect of this extension has been to increase the percentage of coal recovery, for by strip mining no coal is left in roofs, pillars, or panels, and with careful mining substantially all the coal can be taken; a loss of only 5 to 10 percent is not exceptional.[47] The obvious disadvantage of strip mining is destruction of surface land. Unless special precautions are taken for restoration, topsoil, clay, and rock become mixed together in jumbled heaps vulnerable to erosion and further devastation. In general, methods of rehabilitation applicable to areas of subsidense apply also to strip-mined areas.

There are numerous losses of coal not directly attending mining operations. Isolated patches of coal are left in the ground for various reasons. Often the owners of the reserves refuse to sell or lease their holdings to a mining company engaged in a field, or the coal is allowed to remain because it lies under a cemetery or a town.[48] If such areas are small, the coal may never be recovered.

A similar problem arises in connection with premature abandonment. Up to 1923 the coal industry was growing (very slowly in the years after the war), and in addition a large excess capacity was being created. The subsequent decline in the long-term trend of the industry, with the increasingly severe competition resulting, led to bankruptcy for a considerable proportion of the mining companies and to wholesale abandonment of mines before the reserves in the holdings were exhausted. For the period from 1923 to 1932, N. G. Alford recorded 4,802 such abandonments east of the Mississippi River and outside Ohio,[49] and many of the mines no doubt were in such poor condition at the time of the shutdown that they never will be reopened.

These losses in old areas indicate a need of planned and stable development of mining activity. Perhaps it is not too much to insist that every mine opened shall have a definite plan for development coordinated with the plans of other companies so that wasteful exploitation may be reduced to a minimum. An even more important need is the filing of accurate maps with an authorized repository to facilitate future mining of reserves in the event of abandonment by the original operators.

In areas of rough topography or pitching beds, a mine may begin at shallow depths, and, as the work progresses into the hillside or angles downward, greater depth is reached. This increasing depth leads to higher costs of mining and frequently also to need of a change in the system of mining. Whereas widely spaced or small pillars and light timbering, or even strip mining, may be adequate for mining coal near the surface, heavier pillars and heavier timbering are needed for the deeper coal, as well as a longer haul, and perhaps more pumping of water. Greater pressure also adds to the hazards of mining. The operator may have the alternative of following the contour of the coal bed for long distances, perhaps several miles, from the mine mouth or of sinking shafts to the deeper portions. Either way, the cost of mining is increased. Rather than incur this higher cost, some operators abandon the deeper coal. There is, of course, an economic limit to the depth of mining. Some beds down thousands of feet may never be mined or at least not until the more accessible ones have been exhausted. The reservation of entire beds, however, does not aggravate the problems of future recovery, since patches of coal are not thereby isolated and access is not rendered more difficult.

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[42] *Ibid.*, p. 1869.

[43] *Ibid.*

[44] A. Bement, *Illinois Coal*, Illinois State Geological Survey, Bulletin No. 56, 1929, pp. 21 and 38–40.

[45] *Report of the United States Coal Commission, 1925*, p. 1871.

[46] O. E. Kiessling, F. G. Tryon, and L. Mann, *The Economics of Strip Coal Mining*, U. S. Bureau of Mines, Economic Paper 11, 1931.

[47] H. E. Culver, *Preliminary Report on Coal Stripping Possibilities in Illinois*, Illinois Geological Survey, Cooperative Mining Series, Bulletin 28, 1925.

[48] Bement, *op. cit.*, p. 40.

[49] "Analysis of Bituminous Coal Mines Suspended from 1923 to 1932, Inclusive," *Transactions of the American Institute of Mining and Metallurgical Engineers*, vol. 108, 1934, pp. 476–88. During the period 1910–1921, there were 2,978 abandonments of commercial mines in the United States; see United States Coal Commission, *op. cit.*, p. 231.

Similarly thin or dirty portions of a bed may go unmined. For a time, introduction of large, cumbersome machines threatened to increase concentration of mining in thick and relatively clean beds. Fortunately, this outlook has been altered in the past several years when lower and more flexible machines have been perfected. In fact, some coal-mining-machinery manufacturers have been featuring machines adapted for working dirty beds or that can be used in narrow spaces and in thin coal. The universal type of cutting machines, and more recently, the low mobile loaders have aided mining of coal that formerly was irrecoverable by machine. This trend of development is most promising for reduction of coal losses and should be strongly encouraged by the industry as well as by government. Even subsidization might be justified.

In some quarters a fear is expressed of the effects of mechanization of mines. Unemployment of miners is pointed out as one of the serious results, and the ability of hand miners to take coal under variable conditions and leave the refuse in the mine is considered an advantage over machine methods. This argument, although applying to some extent at the present time, carries less force than it did a decade or two ago. Today the bulk of the coal is being undercut by machines (preparatory to breaking it loose from the bed), and loading machines, although not yet used in most mines, are increasing rapidly in number. Consequently, as coal mining is pursued at present, mechanization is in the nature of an accomplished fact; and the suggestion made for encouraging the perfection and use of machines for obtaining a higher recovery of coal is one for turning the tide of technological change to better account.

It is conceivable that machine mining may extend the horizon of profitable mining into beds that formerly could be worked only at heavy loss. Few thin beds are being mined under current conditions, and a decrease in thickness of coal being worked is often a signal to cease activity. Low machines may be able to continue work where hands-and-knees mining would be unprofitable. Although only a small tonnage is mined in the major producing fields, either by hand or by machine in beds as thin as 3 feet, several types of cutting and of loading machines are now made for use in beds only 30 inches thick.[50] There is little question that machines for thin beds will be entirely successful in the near future. Since hand mining in cramped positions is physically tiring and yields low output, application of mechanical power for mining thin beds will be especially advantageous if technical features of the machines are satisfactory. It is undoubtedly more difficult to construct a complicated machine, such as a mobile loader, for use in thin beds than the simpler auxiliary machines; scrapers and face conveyors, both rather simple mechanisms, permit mining of thin beds that are otherwise economically unworkable.[51]

Despite certain advantages of machine mining in aiding recovery of coal, the net effect has not always been favorable to conservation. Cutting machines have been used extensively for many years. They were the chief means for undercutting the beds (to allow for expansion when the coal is broken down) at the time of the Coal Commission study in 1923; this aspect of mining remains substantially the same as it was then. These machines have probably never had much effect on recovery.[52] The fine cuttings of coal ("bug dust") produced by cutting machines have a counterpart in the considerable amount of fine coal yielded by pick mining. When the coal industry was young, nearly all the fine coal was left in the mine or thrown on the refuse pile outside as an unmarketable product.[53] This loss, however, was a large factor, mainly before the late 1880's when cutting machines began to be used.

Rapid adoption of loading machines in the period since 1923 has introduced a new phase of mechanization. The effect of these machines with regard to thickness of beds has already been considered, and it was seen that the recent tendency has been favorable to the mining of thin beds. Another desirable aspect is that the loaders are most efficient in connection with concentrated production where operations are better planned, thus reducing losses of coal from squeezes of overlying strata.[54] On the other hand, mechanical loading is less adaptable than hand loading. Hand shovelers may cast aside slate and clay, thereby keeping the coal relatively clean. But unless special precautions are taken to exclude debris, or unless the bed is unusually pure, the machines load the impurities as well as the coal. Consequently, more cleaning of the coal at the surface is required, and losses may occur there. A strong temptation exists also to concentrate on keeping the machines employed at the work they are best suited to handle and in this effort to neglect other portions of the coal. Top coal and special pillars are often left specifically to protect the machines from roof falls.[55] The incentive to safeguard the machines and to keep them employed at volume production becomes stronger than that of high recovery. Mechanization may work either in the direction of conservation or in that of larger loss; therefore, a blanket decision for or against use of machines in mines is inadequate. It is entirely logical from the standpoint of conservation to encourage the development and use of certain forms of mechanization and to discourage other forms. Further investigation is needed to gauge accurately the effects on conservation of specific types of mechanization.

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[50] Cf. *Coal Age*, June 1937, pp. 271–72.

[51] Rice, Fieldner, and Tryon, *op. cit.*, p. 20.

[52] *Ibid.*

[53] D. C. Ashmead, *Anthracite Losses and Reserves in Pennsylvania*, Topographic and Geologic Survey, Department of Forests and Waters, Commonwealth of Pennsylvania, Bulletin M-8, 1926, p. 66.

[54] *Ibid.*

In general, machine mining is best adapted to level or nearly level beds, where concentrated mining may be undertaken. Coal in steeply pitching beds, such as those encountered in the Pennsylvania anthracite region, is mined with a large proportion of hand labor. It has been observed that the Coal Commission engineers in 1923 calculated the unavoidable losses in the anthracite region at 30 percent, a proportion almost twice as high as that for bituminous coal. Actual losses for anthracite were, in terms of the percentage of the content of the bed being worked, only about nine points higher than estimated unavoidable losses. Undoubtedly, this small difference was calculated on the assumption that existing techniques of mining would be substantially undisturbed. Perhaps much would be gained by application of new systems of mining, for example, the systems used in metal mines. D. C. Ashmead, who was in charge of the Coal Commission's study of anthracite losses, suggests the adaptation of the top-slice method for metal mining to anthracite mining. In a special statement prepared for the current study, he described the method as follows:

> Systems of mining used in the Anthracite Region have in general been similar to or identical with those used in the bituminous coal fields, although conditions in the two fields are entirely different. While mechanization has taken place and machinery is now doing much of the work that was formerly done by hand, the basic methods of mining anthracite are still the same as they were some 50 to 75 years ago.
>
> In the Anthracite Region steep-pitching measures exist similar to those found in the metal fields. It seems reasonable to assume, therefore, that methods used in metal mining might be of considerable value in anthracite mining, but to date none has ever been tried.
>
> Considerable improvement could be made in anthracite mining, and it is suggested that at least one metal mining system, known as the top-slice method, should be tried. This system has many variations owing to the different conditions encountered and no description will be attempted, other than to call attention to what might be expected as a result of its introduction. It can be used on steeply pitching beds, where the pitch exceeds 45 degrees. The thickness of the bed should be more than eight to ten feet, although thinner beds might be worked. It is a retreating system of mining: starting from the top, mining is conducted downward, each individual slice being removed by horizontal mining. There is no underhand or overhand stoping. All of the coal is removed with each slice, so the recovery would be 100 percent, as against a present recovery of 65.4 percent for the whole anthracite region and only 58.9 percent for the western middle and southern fields, which contain the thickest and steepest pitching beds. The actual cost of production, after the system has once been established, would probably be as low or lower than by present methods. Work could be concentrated, and haulage costs thus reduced to a minimum. The percentage of large sizes recovered would tend to be greater than in any of the present steep-pitch systems of mining. Fewer explosives would be required, and it would do away with running coal. No rock from roof or bottom could get into the coal, and the only rock that would be sent to the surface would be bed rock. Haulage and preparation costs would thereby be lessened. Against this, however, more timber would be required, particularly at the start, and more preliminary narrow work necessary in driving raises through the measures. It might even be possible advantageously to return the waste rock to the mine.

One of the underlying reasons for waste in coal mining—both bituminous and anthracite—has been, since 1922, the chaotic condition of the industry. Little improvement in reduction of losses under private operation can be expected until the industry is placed on a stable basis, as indeed the National Bituminous Coal Commission is now attempting to do in the bituminous coal industry. No similar effort is under way for the anthracite industry. Coal mining has been characterized by a downward trend of production, at least back as far as 1923. The mortality rate of operators has been high, and survivors have had to fight too strenuously for continued existence to devote much attention to experimentation and conservation of reserves. Instability appears in several forms in addition to that represented in high turnover among operators. Numerous mines have not been operated at a sufficiently high percentage of capacity to maintain them in good condition.[56] Seasonal swings of output and their adverse effects on operators scarcely able, or actually unable, to bridge the gap of the slack season have been a further factor. The industry also has suffered in common with other industries from cyclical ups and downs of business activity. Finally, the intensified struggle for existence of operators and miners has resulted in strife, with loss of income and depreciation or damage of reserves and equipment. A virtually insolvent industry cannot apply methods of mining with a view to keeping waste at a minimum, even though it desires to do so, nor shoulder costs involved even though they be modest. Stabilization of the industry would undoubtedly have some direct bearing on the reduction of loss.

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[55] *Ibid.*

[56] Cf. Ashley's discussion of "lack of continuous operation," pt. three, sec. I, this volume.

The question of solvency leads to a consideration of the costs of conservation. One proposal for regulation is based on a trade of favors. The central idea is that the industry be given a price per ton high enough to cover costs of mining the less accessible portions of the bed in return for mandatory recovery of such coal. This method would be aimed to protect operators against loss on high-cost production and would have the effect of increasing profits on low-cost production. Actually it confuses the motivation of unregulated industry with the social aim of regulation. The limit of conservation as practiced by coal operators tends to be set by the marginal cost of mining increasingly difficult portions of the bed, whereas to economic groups in general the critical factor is the effect of conservation measures on the average cost of energy. This difference may be illustrated simply by a hypothetical example in which the costs of mining are considered to be at only two levels. Assume that 70 percent of the coal is mined at a cost of one dollar per ton, and the remaining 30 percent at a cost of two dollars per ton. Thus the price needed to induce recovery of the high-cost coal without any coercive action is, under the given assumptions, two dollars per ton. On the other hand, sharing of the cost of conservation by the consumers requires a price of $1.30 per ton, or only 30 cents above the minimum price. This contrast exemplifies one of the major differences in concept between regulated and unregulated industry. It seems probable that, under a voluntary system, inducements needed to effect thoroughgoing conservation would have to be excessively remunerative to coal producers and therefore overburdensome to coal consumers; whereas equitable sharing of costs of conservation may result in smaller average increases than is often supposed.

Coal mining in an enterprise system lacks the basic character necessary for the degree of conservation best suited to the public interest. Losses from waste are certain to react unfavorably on the national economy, whereas private operators may profit most by applying socially wasteful methods. This is true, not because of a malicious intention on the part of operators, but because their chief interest necessarily lies in maximization of gains, an interest not wholly compatible with the social objective of conservation. But fortunately some compatibility does exist. Wastage resulting from mismanagement is a source of loss both to the individual operator and to the public.[57] The depressed condition of the coal industry during the past one and one-half decades has not been conducive to good management. In fact, under the stringent circumstances of the moment, operators have been compelled to resort to wasteful practices that they would be first to criticize from a long-run point of view. By mining only the most readily available portion of the reserve, they have been able to minimize current outlays, although the ultimate result is either higher costs of mining or a compulsory shift of operations to a new location.[58] Stability of enterprise is therefore essential for maximum conservation under private auspices. Operators, of course, cannot be expected to reduce waste beyond the point that will best serve their long-run profit interests. Even if many be guided by altruistic motives, there are close limits to what they may do individually. A burden of only a few cents a ton, if not shared by competitors, may be sufficient to drive them out of business. Accordingly, the most effective means for attaining a considerably higher measure of conservation is through governmental action. Since production of coal is scattered among 31 States, action by a single State without similar action generally in the industry will weaken the competitive position of that State. For this reason, a State cannot well afford to take the initiative to promote conservation. Primary responsibility can best be taken by the Federal Government for that part of the conservation burden required to be borne publicly.

An accounting of gains and losses from higher recovery shows items on both sides of the ledger not only for coal consumers but also for coal producers. In some respects higher recovery reduces costs of production in the long run. This is true of costs that vary with the area of the coal land. If recovery is high, a smaller area is needed for a given tonnage production. Hence larger recovery reduces the charge per ton for amortization of a lump-sum payment per acre for purchase of coal lands or of mining rights. Likewise, the smaller the area of mining, the lower the outlays for such items as haulage, ventilation, pumping, tipples, hoisting equipment, and property taxes. An increase in recovery from 60 to 90 percent would reduce these items one-third for each ton, assuming an exact correlation of costs with area. The incentive is greatest, of course, where these area costs are highest. In fact, it varies in direct proportion to the level of the costs. On the basis of Campbell's calculation of 1,770 net tons of coal in an acre of coal one foot thick,[59] a total allocated cost of $2,000 per acre would amount to about 28 cents per ton for a bed four feet thick, assuming full recovery of the coal. An increase in recovery from 60 to 90 percent would result in a cost reduction of 16 cents per ton.

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[57] Cf. *Report of the U. S. Coal Commission, 1925,* pp. 1931–1932 and 1935.

[58] Rice, Fieldner and Tryon, *op. cit.,* p. 31.

Low recovery, with consequent spreading of operations, results in a cumulative increase in some cost items. At first little or no additional cost is incurred, but as the workings penetrate farther from the mine mouth, a larger network of tracks must be built and more time, transportation equipment, and power are consumed in haulage. Eventually costs may reach a point at which mining is no longer profitable, or the entrance to the mine has to be moved, probably away from an established mining town and developed surface facilities.

Against these savings are items of cost that increase when more of the coal is mined. Cost of timbering to support the roof, probably labor costs, and damage from subsidence will increase. These factors are so highly variable that general estimates of their magnitude are not available. Where the mine roof is strong and little damage from cave-ins occurs, the cost may be exceedingly small; but where the roof is weak or the surface land is valuable, as in most of the coal fields of Illinois, Iowa, Missouri, and Kansas, the cost may mount at times to prohibitive heights. The cost of supporting surface structures is usually large, but, as has been seen previously, losses of coal in pillars left to support such structures are, in general, small. Coal and lignite deposits underlie 458,000 square miles of continental United States,[60] or more than one-seventh of the total area of the country. Vast areas have not merely one bed but two or more. Sometimes seven or eight minable beds are found, as in Butler, Clarion, Fayette, and Somerset counties in Pennsylvania.[61] In the main, the top beds are mined first, often near the surface where there is the greatest problem of subsidence damage.

Restoration of farm lands damaged by undermining, however, is commonly an easy task, particularly where the land has sufficient slope for drainage but not enough slope to cause erosion after subsidence has occurred. Complete mining of coal coupled with systematic restoration of the land might simplify the problem of damage. A comparatively uniform subsidence decreases the amount of leveling required. Thus, in many instances, full recovery might cause less injury than the current practice under which sags, pit-holes, and cracks are common despite the leaving of pillars.[62]

The cost of damages, even where the land is rich and very flat, is seldom more than a few cents a ton.[63] An out-of-pocket outlay of $150 per acre for damages often seems like a heavy penalty, but it is generally a minor item of cost. A bed of coal four feet thick contains about 7,080 net tons of coal per acre.[64] If the entire cost of $150 per acre for surface damage be allocated on a tonnage basis for a 4-foot bed, the cost is only 2.1 cents per ton, a modest price to pay for conservation. Studies of actual damages in coal fields, particularly in Illinois, show a similar low cost per ton.[65]

But operators are confronted in many instances not so much with the actual cost of the damages as with the sum involved in extravagant awards in damage suits.[66] Unless the coal producer owns the surface land as well as the coal rights, or unless the land owner waives rights to claims for damages, the operator may have to meet the costs of litigation and in addition pay heavily for any destruction. Rather than become involved in this extra cost, companies often choose to leave pillars of coal in the ground to support the surface. Usually the damage to farm land is temporary and can be restored effectively. This needless loss of coal should be reduced by limiting the obligation of the operators to restoration of the property or to an equivalent cost.

Thorough mining of coal—all items of loss or gain considered—usually does not increase the average cost of mining to a marked extent. Although cost data are meager, it is the judgment of leading authorities that at most mines the increased cost involved in pillar recovery—the principal factor—should be much less than 10 percent.[67] The general question is summarized as follows: "It is believed that the addition to average cost through complete recovery of pillars would rarely, if ever, exceed 25 cents a ton at present wage scales, that at the great majority of mines it would be less than 10 or 15 cents a ton, and that at many other mines there would be no significant increase in cost. At still others, pillar extraction remains the most profitable practice. If the existence of local exceptions is recognized, it seems clear that most of the present enormous loss of bituminous coal in pillars could be avoided at a very modest advance in operating cost." [68]

The more progressive companies in the Appalachian and Rocky Mountain areas usually recover coal pillars.[69] But with losses of about 35 percent in bituminous coal mines and even larger losses in anthracite mines, some positive action toward conservation seems advisable.

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[60] M. R. Campbell, *Coal Resources of the United States*, United States Geological Survey (multigraphed report).

[59] Rice, Fieldner, and Tryon, *op. cit.*, p. 25.

[61] George H. Ashley, *Bituminous Coal Fields of Pennsylvania*, Pennsylvania Geological Survey, Bull. M-6, pt. 1, 1928, pp. 158–159.

[62] Rice, Fieldner, and Tryon, *op. cit.*, pp. 28–29.

[63] *Ibid.*, p. 29.

[64] Campbell, *op. cit.*, estimates 1,770 net tons per foot-acre. Some differences exist, of course, owing to variations in density of the coal and in amount of moisture and impurities in the bed.

[65] Rice, Fieldner, and Tryon, *op. cit.*, p. 29.

[66] *Ibid.*, p. 30.

[67] *Ibid.*, p. 27.

[68] *Ibid.*, p. 28.

It should be remembered that these estimated costs of fuller recovery are expressed as a percentage of the average. Hence they indicate the magnitude of the added cost per ton in the nation's fuel bill, but they do not indicate how much incentive must be held out to induce operators voluntarily to increase the percentage of recovery. Obviously a 10 percent increase in the price of coal would not be applied by operators entirely toward conservation, even though a 10 percent rise would be adequate on the average to cover the added cost of substantially full recovery. Accordingly, methods of distributing the cost of conservation must be devised to attain the intended objective. These methods are discussed in the succeeding chapter.

Conservation in Use

Unlike wastes in mining, which probably have not decreased since the World War and which may have increased, the progress of fuel efficiency has continued unabated. The principal consumers of coal, such as steam railroads, electric power plants, and the iron and steel industry, have made substantial reductions in consumption of coal per unit of work performed. This form of conservation increases the potential usefulness of coal resources quite as much as elimination of wastes in mining. The work obtainable from the resources by present-day methods is far greater than it was in an earlier period, and no doubt the usefulness of these resources will be further enhanced by improvements in the future. As a consequence, every ton of coal conserved will grow in usefulness, so that its full significance will not be adequately indicated by current standards of consumption but by higher standard yet to come.

Improvements in the efficiency of coal use have occurred for a variety of reasons, which, for the purpose of this discussion, may be considered under the headings: (1) growth of knowledge of the composition and properties of coal, (2) improvements in the physical adaptation of coal to specific uses, (3) introduction of economies in conversion of coal to heat energy, (4) introduction of economies in conversion of coal to mechanical energy, and (5) reduction of energy required for a given purpose.

Improved Knowledge of the Nature of Coal

The old idea that coal is merely something to burn has long been supplanted. The composition of coal is so highly complex that no two pieces are exactly the same in composition. Coal is the source, in part, of thousands of products ranging from flavoring extracts to explosives. A vast amount of chemical and engineering research lies behind the present use of coal. Chemical research is concerned largely with (1) reactions involved in the utilization of coal in conversion processes, such as carbonization, hydrogenation, gasification, and combustion, in which the end is energy production, and (2) utilization of coal as a raw material for the chemical industry. The nonfuel side of coal utilization is one that should not be overlooked. Conservation of coal means conservation not only of the energy supply but also of an inestimable quantity and variety of synthetic products. It is possible that in the distant future coal energy may be a byproduct of a vast chemical industry producing organic nonfuel compounds. Engineering research, on the contrary, is concerned with developing techniques for the physical handling of coal or its derivatives. In general, it presupposes a solution, on a laboratory basis at least, of the chemical problems involved.

The long-run importance of basic research on the composition and properties of coal can hardly be overemphasized. Techniques of use may change rapidly, but all of them have to contend with the composition and properties of the coal resources. The existence of relatively abundant coal reserves in the United States has discouraged basic coal research. Investigations leading to the development of the byproduct coke industry were far along in Germany and England before the industry was established in the United States in 1893. It was not until 1904 that the first Nation-wide survey of the composition and properties of coals affecting their utilization was made in the United States.[70] After this initial effort, the work was continued by the Technologic Branch of the United States Geological Survey and by the Bureau of Mines, beginning with its establishment in 1910.[71] Investigations have since been conducted continuously by the Bureau of Mines; and the results published in numerous technical papers provide a vast fund of fundamental information for improvements in coal utilization. In addition, State departments of mines and research laboratories maintained by universities and private concerns have contributed to knowledge needed for better use of coal. The Coal Research Laboratory of Carnegie Institute of Technology has made detailed studies of the constitution of coal, and the Institute also has sponsored international conferences at which much of the outstanding research on bituminous coal in the United States and in foreign countries has been discussed. Probably more than 40 laboratories in the United States are engaged to some extent in research on coal and coal utilization, and at least 10 of them are major contributors to information on coal and to advances in coal technology.[72] Despite this extensive work, much remains to be done.[73] Beginning in 1932 and continuing until 1937, A. C. Fieldner, of the United States Bureau of Mines, gave, in *Minerals Yearbook*, reviews of the progress of fundamental and applied research in coal.

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[69] T. G. Fear and H. N. Eavenson, discussion in *Transactions, American Institute of Mining and Metallurgical Engineers, 1931*, p. 202.

[70] Survey by the fuel-testing plant established by the U. S. Geological Survey at the Louisiana Purchase Exposition in St. Louis; Rice, Fieldner. Tryon, *op. cit.*, pp. 36–37.

[71] *Ibid.*, p. 37.

One of the most absorbing aspects of this research has been the effort to develop classifications and standard grades and specifications. Efficient utilization of coal requires proper selection and preparation. Detailed research on the constitution of coal, although it lays the groundwork for improved technology, usually has made available a mass of detail not suitable as a common language among producers, distributors, and consumers of coal. There is accordingly a need for an accurate but reasonably simple description of the properties of coal most significant to the coal trade. What is the heat value, ash content size, and friability of the coal? Even though coal resources have variable characteristics, some degree of specification is requisite for efficient utilization. From the standpoint of utilization, the chief factor is not a certain tonnage of coal but rather how effective the coal may be per unit of cost in accomplishing the purpose. One ton of coal with a heat value of 14,000 B. t. u. per pound may be more effective for steam-raising purposes than two tons of 7,000 B. t. u. When coal-consuming equipment has been adjusted to a certain grade of coal, uniformity and proper selection of coal may be needed for maximum efficiency. It is seen, therefore, that classification may result in higher efficiencies. It may also eliminate double testing.

Although coal has been bought and sold for many years on a specification basis by establishments with facilities for testing the shipments, and although schematic classifications have been available also for some time,[74] it is only within the past few years that the American Society for Testing Materials has issued standardized ratings.[75] More recently, the Consumers' Counsel of the National Bituminous Coal Commission has advocated strongly the adoption of standards in the coal trade.[76]

In general, coal classifications deal with two problems: (1) classification of coals as they occur in the ground, that is, classification by rank, and (2) classification of coals after they have been mined and prepared for the market, that is classification by grade. The American Society for Testing Materials has established generally acceptable boundary lines for the classes.[77]

Improved Adaptation of Coal to Uses

When coal is mined and prepared for the market its condition is altered considerably even if it is not converted to another form such as semicoke or coke. At the mine face, the solid coal is broken down into all ranges of size from slack to large lump, and, there also, much of the rock and clay is discarded onto the refuse pile, or gob, in the mine. Further preparation usually takes place at the surface. Although some coal is sold as run-of-mine, or with only a small amount of screening, the proportion disposed of in this form undoubtedly is decreasing. Nearly all the anthracite and a large proportion of the bituminous coal is sized and cleaned before it is marketed. This work, particularly sizing, is now very largely mechanized. When the lumps of coal are large and slate adheres to them, hand picking has advantages over other methods, but, otherwise, ingenious mechanical methods are widely used. The mechanical methods effect a separation by taking advantage of differences in specific gravity, aided sometimes by such characteristics as differences in shape and outward physical structure, for example, angularity or roughness. The tendency of lighter particles to separate from heavier particles when subjected to a current of air or water, or to centrifugal force (as in cream separators), and when floated in liquids of proper density is a well-known fact—one applied in mechanical coal-cleaning plants. Methods in use are classified as (1) wet and (2) pneumatic methods. Experimental jigs (using a wet method) were installed in the Pennsylvania anthracite fields about the time of the Civil War, and some 10 years later more extensive installations were made in the anthracite field, in the Pittsburgh district, and in southern Illinois.[78] Pneumatic cleaning began in 1919.[79] In 1906 the United States Geological Survey began to record the quantity of coal washed at bituminous coal mines and found the amount in that year to be 2.7 percent of national production.[80] The proportion of bituminous coal cleaned by both wet and pneumatic methods was 7 percent in 1929 and about 15 percent (estimated) in 1937; but 1 percent in 1929, and probably a larger percentage in 1937 was at plants operated by consumers, not at the mine (fig. 24).[81] In 1930 and each subsequent year slightly more than 20 percent of the mechanically cleaned bituminous coal has been handled by pneumatic methods.

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[72] Arno C. Fieldner, "Recent Developments in Coal Preparation and Utilization," *Minerals Yearbook, 1937*, pt. III, p. 935.

[73] *Ibid.*

[74] See, for example, George H. Ashley, "A New Classification of Coal," *Transactions, American Institute of Mining and Metallurgical Engineers, 1919*, pp. 1125–41.

[75] American Society for Testing Materials, "Tentative Specifications for Classification of Coals by Rank and Grade," *Proceedings*, vol. 34, pt. I, 1934, pp. 834–842. H. J. Rose, "Coal Classification," *Industrial and Engineering Chemistry*, vol. 26, 1934, pp. 140–143. A. S. T. M., *Proceedings*, vol. 35, 1935, pp. 847–853, and vol. 36, 1936, pp. 812–818. A. C. Fieldner, "American Standard Sets Up Common Language for Coal," *Industrial Standardization and Commercial Standards Monthly*, vol. 7, 1936, pp. 273–278. *A. S. T. M. Standards on Coal and Coke*, published by the American Society for Testing Materials, 1938.

[76] Consumers' Counsel, National Bituminous Coal Commission, *How Much Heat in Bituminous Coal*, Consumer Ideas Number One, 1937; also its *Classification Standards and Their Application*, April 8, 1938 (mimeographed).

[77] Arno C. Fieldner, *op. cit.*, *Minerals Yearbook, 1937*, pt. III, pp. 935–36.

[78] L. N. Plein, *Statistical Analysis of the Progress in Mechanical Cleaning of Bituminous Coal from 1927 to 1934*, Economic Paper 18, U. S. Bureau of Mines, p. 1.

Mechanical cleaning of coal was given a new impetus after 1923 by the rapid growth of mechanical loading. With certain types of loading devices there is little or no opportunity to clean the coal at the mine face, and as a result the need of mechanical cleaning becomes more urgent.[82] But it is probably true that cleaning has developed also in response to growing demand for a purer product.

In addition to this cleaning, coal preparation includes dehydrating, drying, special dedusting by wet or pneumatic methods, dust-prevention treatment with oil, calcium chloride, and other agents, as well as packaging and briquetting.[83] Briquetting with combustible material adds slightly to the fuel value of the coal, so that the product is not strictly a raw coal fuel.

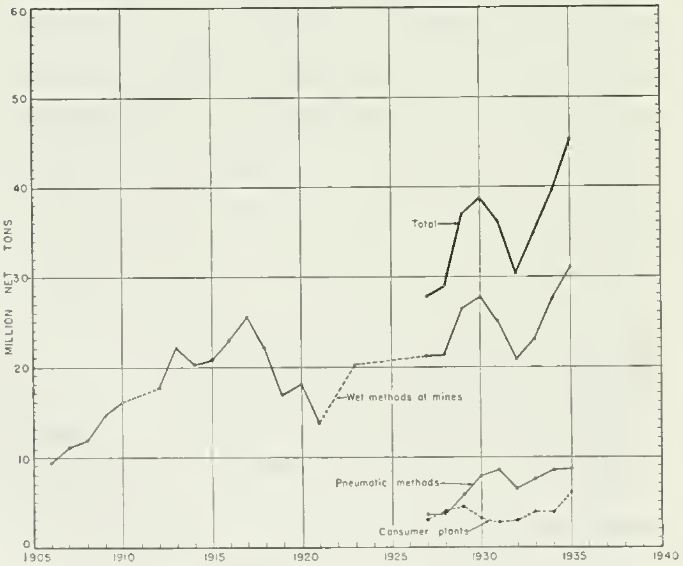

FIGURE 24.—Tonnage of Bituminous Coal Mechanically Cleaned in the United States, 1906–35. (Reproduced from *Minerals Yearbook, 1937*, p. 837.)

A step further advanced than the development of a better fuel by preparation of coal is improvement by processing. Viewed solely from the standpoint of efficiency in use, coal converted to a gaseous form gives the best results, and second best is a liquid fuel produced from coal. In the United States, and other countries as well, the bulk of the conversion is to coke. The byproduct coke process has been a boon to conservation by recovering byproduct gas, oils, and nonfuel products, all wasted in beehive ovens, and also by yielding a higher percentage of coke. A ton of coal used in byproduct ovens yields 9 gallons of tar, 22 pounds of ammonium sulphate, 3 gallons of light oil, and 11,000 cubic feet of gas in addition to about three-quarters of a ton of coke and coke breeze.[84] In years of active business, about four-fifths of the coke produced in the United States is consumed by the iron and steel industry. Growth of coke consumption for domestic (household) purposes seems to have been halted by increased consumption of natural gas and fuel oil and by introduction of stoker-fired coal furnaces. At any rate, coke consumption for domestic purposes was lower in 1936 than in 1935, even though consumer incomes were higher. The higher price for coke than for bituminous coal, and, in some sections, for anthracite, is a deterrent to expansion of sales, but the lack of a good market in the United States for byproducts is an obstacle to reduction of the price of coke to a level at which a strong inducement for consumption of coke is provided. In 1936 the average gross receipts from byproducts per ton of coke produced was only 54 cents for tar sold or used, 29 cents for ammonia and its compounds, 43 cents for light oil and its derivatives, and $1.59 for surplus gas sold or used.[85] The higher efficiency in use of coke-oven gas, oils, and coke than of raw coal is partially canceled by thermal losses in the byproduct ovens. Very likely for the more wasteful utilization of coal fuel, as in hand-fired residential furnaces, conversion of coal first by the byproduct process is distinctly a conservation measure as well as a means for combating the smoke hazard in cities.

A disadvantage of the ordinary high-temperature coke process is that it usually utilizes high-rank coal. Some of the low- and medium-temperature carbonization processes can use low-rank bituminous coal or lignite. The product is usually a smokeless semicoke more easily ignited than high-temperature coke. Since the low- and medium-temperature processes, as a rule, yield more oils than the usual byproduct processes in use today,[86] the handicap of a low price for byproduct oils appears in magnified form. Accordingly, a larger market for tars and other byproducts will encourage increased production of coke and semicoke, solid fuels highly desirable from the standpoint of utilization.

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[79] *Ibid.*, p. 3, table 1, footnote 3.

[80] *Ibid.*, pp. 1 and 3.

[81] Based on data from *Minerals Yearbook, 1935* (statistical appendix), pp. 272–73, and *1938*, pp. 688–89. See also Plein, *op. cit.*, p. 3.

[82] Plein, *op. cit.*, p. 19.

[83] Fieldner, *op. cit.*, *Minerals Yearbook, 1937*, pp. 941–42.

[84] *Minerals Yearbook, 1937*, pp. 893–94.

[85] *Ibid.*, p. 896.

[86] Arno C. Fieldner, "Fuels of Today and Tomorrow," *op. cit.*, p. 14.

Production of liquid fuels from coal often has been hailed as a means of obtaining a better fuel and of relieving the pinch when petroleum resources are inadequate to meet demands. Although it is possible to produce liquid fuels from any rank of coal by hydrogenation,[87] experiments over an extended period in the United States and abroad have been disappointing in regard to the economic feasibility of the undertaking. No hydrogenation is being done on a commercial scale in the United States. Costs of refined motor fuel from coal are far higher than those of gasoline from petroleum. They have been estimated as low as 11 to 12 cents per gallon at the plant,[88] against a current cost of gasoline at the refinery of only four or five cents. Moreover, hydrogenation is definitely not a way of conserving the heat values in coal. The thermal efficiency of the Billingham plant in England, one of the few active hydrogenation plants in the world, is only 40 percent.[89] This efficiency is below that of wasteful hand-firing of small residential furnaces.

Gasification of coal has had a greater development than hydrogenation. In many cities, gas manufactured chiefly from coal is the only kind available, but it remains an expensive source of energy, generally much more so than natural gas. The cost per thousand cubic feet is frequently twice that of natural gas, and the heat value is usually about half as great. Thus, on a heat-value basis, the cost ratio is four to one. Because of growing abundance, natural gas has cut into the market for manufactured gas and promises to make further inroads in the near future.[90] Unless revolutionary cost-saving changes are made in the gasification of coal, exhaustion of the supply of natural gas will be a severe blow to gas consumers.

The use of producer gas as a motor fuel is being given a trial in Germany, England, and France.[91] Wood charcoal is the most desirable fuel, but anthracite and low-temperature coke also are satisfactory. Portable producers for a 5-ton truck include steel cylinders 12 to 20 inches in diameter and 4 to 6 feet high, weighing about 200 pounds. The cost of the solid fuel is only 10 to 20 percent of that of gasoline, but, of course, gasoline prices are far higher than in the United States. Maintenance costs are about the same as for gasoline-driven vehicles. In Germany over 1,000 producer-equipped trucks and busses were in operation at the end of 1936. In England a producer-equipped truck gave a cruising range of 300 miles on one filling of anthracite, and a bus successfully operated on Welsh anthracite and one type of low-temperature coke, with a consumption of coke (when it was used) of only about 2.2 pounds per mile. At a price of $8 per ton for coke, the cost of fuel then would amount to only nine-tenths of a cent per mile. This cost is extremely low measured even by American standards of cost for bus operation; but lowered performance, owing to relatively inflexible operation, is a disadvantage where stress is placed on speed and dispatch.

In considering economies in the actual conversion of fuel to energy, a distinction needs to be drawn between heat energy and mechanical energy. Losses of potential energy in fuels are far less in the production of heat than in the production of actuating, or mechanical, energy. The latter is one stage further removed in the process of utilization.

Economies in Conversion of Coal to Heat Energy

Some idea of the degree of efficiency in heat production from coal can be gained by the study of the performance of residential furnaces. It is well known, of course, that the efficiency of large installations, such as boilers in central electric power stations, is much higher than that of residential furnaces. A series of tests made by the Battelle Memorial Institute on the heating plants of 15 homes in Columbus, Ohio, gave overall thermal efficiencies with bituminous coal ranging from 41 to 69 percent.[92] The minimum efficiency was recorded for a hand-fired warm-air furnace using bituminous coal; the maximum, for a stoker-fired steam boiler also using bituminous coal. An efficiency of 76 percent, the highest recorded in any of the tests in which coal, coke, natural gas, or oil was used, was obtained for a hand-fired warm-air furnace using coke and also for a steam boiler using natural gas. The results from the actual tests made under various weather conditions were adjusted to indicate probable efficiencies for an entire heating season. These estimated seasonal efficiencies were as follows: 45 percent for hand-fired bituminous coal, 55 percent for stoker-fired bituminous coal, 50 percent for hand-fired semibituminous coal, 70 percent for hand-fired coke, 70 to 75 percent for natural gas, and 60 to 70 percent for oil. A careful study of hand-firing of anthracite in a hot-water residential plant at New Haven, Connecticut, gave an efficiency of 65 percent for a heating season.[93] The largest losses were due to heat in dry flue gases, these ranging from one-third to two-thirds of the total losses.[94] Other losses resulted from moisture, carbon monoxide gas, unconsumed carbon in the ash, and unaccounted causes.

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[87] Cf., C. C. Wright and A. W. Gauger, "The Hydrogenation of Coal," reprint from *Industrial and Engineering Chemistry*, vol. 26, February 1934, p. 164.

[88] C. C. Wright and A. W. Gauger, *Progress Report on Coal Hydrogenation*, Technical Report No. 2, October 1936, Bituminous Coal Research, Incorporated, pp. 13–14. Cf. Committee of Imperial Defense, Subcommittee on Oil from Coal, *Report*, London, February 1938; Gustav Egloff, "Manufacture and Use of Substitute Motor Fuels Is Proving Costly in Europe," *Oil and Gas Journal*, September 8, 1938, p. 56 ff.; *Petroleum Investigation*, Hearings on H. R. 441, September 17–22, 1934, pt. 1, p. 748.

[89] *Ibid.*, p. 10.

[90] Cf. W. H. Fulweiler, "The Future of Manufactured Gas," *Proceedings, Third International Conference on Bituminous Coal*, Pittsburgh, Pa., 1931, vol. I, pp. 157–171.

[91] Arno C. Fieldner, "Recent Trends in Fuels Competition," address given at the First Annual Anthracite Conference, Lehigh University, Bethlehem, Pa., April 29–30, 1938, pp. 7–8 (mimeographed).

[92] Ralph A. Sherman and R. C. Cross, *Efficiency and Costs of Various Fuels in Domestic Heating*, Technical Report No. 3, December 1936, Bituminous Coal Research, Inc., Washington, D. C., p. 32. Cf. R. T. Goodwin, "Fuel-Oil Production and Use," *Oil and Gas Journal*, November 18, 1937, p. 59. For more comprehensive but less recent data, see *Five Hundred Tests of Various Coals in House Heating Boilers*, U. S. Bureau of Mines Bulletin 276; also *Transactions, American Society for Heating and Ventilating Engineers*, vol. 31, 1925, pp. 210–211.

It is seen in these tests that the hand-fired coke furnaces were about 50 percent more efficient than the hand-fired bituminous coal furnaces. This difference in efficiency was such that the cost of fuel for the coke furnaces in Columbus was 13 percent less than for the hand-fired bituminous coal furnaces,[95] and, of course, coke had the further advantage of giving smokeless combustion. Consumers often express dissatisfaction with the results obtained from firing with coke. The main reason for this complaint lies no doubt in improper design of the burning equipment. The ordinary coal furnace is poorly adapted for coke. Whereas a furnace designed for a fuel bed 12 inches deep may give satisfactory results with coal, a depth twice as great may be needed for coke.[96]

From a cost standpoint coke has the greatest relative advantage in consuming centers located at some distance from the coal-producing fields. Since the cost of transportation between the mine and the consuming area varies in proportion to tonnage, the price of coke tends to maintain a fixed differential above the price of coal, if both the coal and the coke follow the same route of distribution. On December 15, 1938, the retail price of egg coke in Pittsburgh was $6.75 or 55 percent higher than the price of high-volatile egg bituminous coal.[97] If the efficiency of coke firing was 50 percent greater than that of bituminous coal firing, obviously coal was the cheaper fuel. In Cleveland, however, where egg coke sold for $9.29 a ton (including a 3 percent sales tax), a level only 22 percent above high-volatile egg bituminous coal, coke was the more economical fuel, assuming the same differences in efficiency. The pattern of regional cost differentials is, of course, highly complex. Nevertheless, the importance of considering at least the chief differences is clearly apparent. Reasons other than economy may also carry heavy weight in the shaping of the fuels policy with respect to coal and coke. Socially, conservation of coal resources is an aspect that may throw the balance in favor of coke, even though direct costs to consumers may be somewhat higher. Smoke abatement and consequent improvement of environmental and health conditions as well as savings in cleaning bills are forceful arguments for the substitution of coke for coal.

A newcomer in the technique of coal utilization is the small coal stoker suitable for residential use. Marked advances in the design of stokers in recent years have opened new possibilities of application. Stoker firing, in addition to giving higher efficiency than hand firing, greatly reduces the volume of smoke emitted. It also possesses the advantage of automatic control of firing. Although the price of stokers is still relatively high, reductions are being made so that such equipment is coming within the reach of a larger group of consumers. Conversions of hand-fired furnaces to stoker firing are not as satisfactory as unit installations. In the programs for new housing, more attention should be given to heating plants, particularly to direct more consideration to stoker equipment where the use of coal is contemplated.

Owing to the added first cost of stokers and to additional expenses of upkeep and of delivery of coal from the bin to the furnace (usually by electric power), stokers are at a maximum advantage with respect to hand firing in areas where coal costs are high. They also tend to be advantageous in cold climates or in large residences where the annual consumption of coal is heavy.

Stoker firing usually costs somewhat more than hand firing, but because of higher fuel efficiency and use of cheaper sizes of coal, the difference is seldom great.[98] Consumers, nevertheless, have been prone to draw comparisons with such luxury fuels as oil and gas, whereas, for some homes, stokers offer all the advantages of clean, automatic heat at a cost about as low as that of hand firing. Despite this assumed luxury status, however, stokers are gaining rapidly in favor. This change is shown by the ratio of sales of stokers to sales of oil burners, which in 1932 was one to eight, but in 1937 was down to about one to two.[99]

In the firing of a small furnace, especially by hand methods, the personal factor enters strongly. Given the same furnace, variable efficiencies are obtained, differences appearing with reference to the type of coal selected, the methods used in firing, and weather conditions. There is a real need for education of consumers on the efficient use of coal-burning equipment. The efforts of the United States Bureau of Mines,[1] the Consumers' Counsel of the National Bituminous Coal Commission,[2] Bituminous Coal Research, Inc.,[3] the Anthracite Institute, and Anthracite Industries, Inc., in this direction are commendable and should be further extended. The chief hope of the coal industry lies in improved service. There is a need for further studies of problems encountered under the common methods of firing. These studies preferably should be broadly based to include costs of fuels, costs of equipment and its operation, insulation of buildings, humidity control, and reduction of dust, smoke, and soot. In this connection, the educational campaign in France to persuade consumers to adopt the most modern and most efficient methods of utilization may warrant close observation.[4]

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[93] L. P. Breckenridge and S. B. Flagg, *Saving Fuel in Heating a House*, Technical Paper 97, 1917, U. S. Bureau of Mines, p. 31.

[94] Sherman and Cross, *op. cit.*, pp. 13–30, *passim*.

[95] *Ibid.*, p. 9.

[96] Breckenridge and Flagg, *op. cit.*, p. 16.

[97] Prices are from *Retail Fuel Prices by Cities*, December 15, 1938, U. S. Bureau of Labor Statistics (mimeographed).

[98] Cf. Sherman and Cross, *op. cit.*, p. 10.

[99] Data from Ralph A. Sherman, "The Status of Coal Research Today," paper presented at the Conference on the Engineering and Economic Utilization of Solid Fuel, Washington University, St. Louis, May 30, 1938, p. 7 (mimeographed).

High efficiencies and almost smokeless combustion are achieved by the use of pulverized coal. Extensive research has been done on this aspect of utilization, more attention having been given to this topic at the Third International Conference on Bituminous Coal, 1931, than to any other subject.

Since pulverized coal is highly combustible, special problems of transportation are encountered. For railroad haulage, specially constructed tank cars are required.[5] Pipe-line transportation has been tried, and installations of about one mile have been worked satisfactorily.[6] In the future, long-distance pipe-line transportation of colloidal solutions of coal may be a possibility. Pulverized coal might conceivably be piped from a central producing plant directly to consuming equipment. Thus, advantages of low-cost smokeless combustion and automatic control would be combined. Use of pulverized coal in locomotive boilers has shown such favorable features as little smoke, no sparks, easier handling of coal, rapid adaptation of firing to variable load, less consumption of coal, and saving in dead-head haulage.[7] Pulverized coal also has been used with moderate success as a fuel for internal combustion engines.[8]

There appear to be great possibilities for better use of coal energy through temperature control in the home. Uncoordinated systems now in use probably some day will seem woefully crude. A central automatic unit, possibly using pulverized coal, may provide all the needs of energy for space heating, water heating, and cooking; or the entire needs for heating and cooling might be met by a single unit operating on the principle of the mechanical refrigerator. Changes equally spectacular have occurred during the past 50 years, particularly in the application of electrical energy. Improvements in the technology of heat energy may be the next major advance.

So far as conversion of coal to heat energy is concerned, maximum possible efficiency is being approached by the best boilers.[9] Both pulverized coal and stoker-fired installations give steam efficiencies of as much as 90 to 92 percent.[10] Accordingly, not much can be done to raise the performance of these boilers, and attention should be turned to raising the performance of the less-efficient installations or, if mechanical energy is desired, to improving the efficiency of conversion of steam to power.

Economies in Conversion of Coal to Mechanical Energy

Although conversion of coal to heat energy may be within 8 percent of absolute perfection in the best installations, losses in conversions to mechanical energy, even on best performance, run to at least 68 percent. The efficiency of mercury-vapor plants on test has gone as high as 40 percent, but in regular operation the maximum is only 32 percent.[11] Steam-turbine plants using coal fuel have been able to attain an efficiency of 31 percent.[12]

Experiments have been made with the use of tar from bituminous coal to operate Diesel motors. A mixture of refined tar oil with 10 percent paraffin oil operated satisfactorily and gave a thermal efficiency of 29 percent.[13]

It should be emphasized that these maximum efficiencies are far above the average performance. Most of the equipment now in use was installed a decade or more ago. At least 56 percent of the railroad locomotives are more than 20 years old.[14] But the thermal efficiency of most of the locomotives built since the World War is probably not more than 11 to 12 percent.[15] Stationary installations, of course, usually show higher efficiencies. The fuel efficiency for railroads could be doubled by electrification, so that the higher efficiencies of central power stations would be utilized.[16] It is safe to assume that the average efficiency of industrial boilers, the majority of which were installed, no doubt, more than a decade ago, is little if any above 65 percent.[17] The addition of air heaters, economizers, and mechanical stokers or powdered-fuel burners may easily raise the average to 80 percent, thereby effecting a substantial conservation of coal.

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[1] Breckenridge and Flagg, *op. cit.*, see also J. F. Barkley, *Questions and Answers for the Coal Fireman*, U. S. Bureau of Mines, 1938; also Barkley, *Questions and Answers for the Home Fireman*, U. S. Bureau of Mines, 1933.

[2] In its "Consumer Ideas" bulletins.

[3] In bulletins, such as *Automatic Residential Heating with Bituminous Coal*, distributed by the National Coal Association.

[4] See H. de Peyerimhoff, "Rational Utilization of French Coal Reserves," *Third International Power Conference*, sec. IV, Paper No. 11, Washington, D. C., 1936 (conference proof), p. 8.

[5] L. P. Goosens, "The Transport of Pulverized Coal," *Proceedings, Second International Conference on Bituminous Coal*, Pittsburgh, 1928, vol. I, p. 969.

[6] *Ibid.*

[7] Baurat Walter Kleinow, "The Powdered Coal Locomotives of the Allgemeine Elektricitaets Gesellschaft," *Proceedings, Second International Conference on Bituminous Coal*, Pittsburgh, 1928, vol. I, pp. 815–16.

[8] See, for example, Rudolph Pawlikowski, "An Internal Combustion Engine Using Pulverized Coal," *Proceedings, Second International Conference on Bituminous Coal*, Pittsburgh, 1928, vol. I, pp. 768–91.

[9] Fieldner, "Fuels of Today and Tomorrow," *op. cit.*, p. 12.

[10] *Ibid.*

[11] *Ibid.*, p. 13.

[12] *Ibid.*

[13] Fieldner, "Recent Developments in Coal Preparation and Utilization," *Minerals Yearbook, 1937*, pt. III, p. 949.

[14] Interstate Commerce Commission, *Statistics of Railways in the United States, 1935*, pp. 5–16.

The history of power production from coal has been one of uninterrupted increase in efficiency. The crude steam engine invented by Savery in 1700 probably consumed 40 pounds of coal per horsepower-hour; the Newcomen engine, invented in 1711, about 35 pounds.[18] Smeaton's engine in 1772 reduced the consumption of coal to 18 pounds per horsepower-hour, and Watt's engine in 1778 reduced it to 9 pounds.[19] The Cornwall engine of 1844 used 3.2 pounds. By the end of the World War the best engines consumed a little more than 1 pound per horsepower-hour, whereas those today consume considerably less than 1 pound for equivalent output. The first steamship to cross the Atlantic, the Savannah, is believed to have burned 10 pounds per horsepower-hour.[20] This record was made in 1819. In 1907 the Lusitania consumed only 1.3 pounds.[21]

During recent years, central electric power stations have made the most spectacular gains in fuel economy (fig. 25). From an average consumption in 1902 of 6.4 pounds of coal per kilowatt-hour, the level has been reduced to 1.42 pounds in 1937.[22] The peak attainment in efficiency is 0.707 pounds of coal per kilowatt-hour.[23] There is therefore a wide spread between the best performance and the average for the country, but the rate of reduction of the spread will be slower than in the past because earlier improvements tended to eliminate methods that were admittedly inefficient. But a plant now using 2 pounds of coal per kilowatt-hour may be highly efficient, if the coal used has a low heat value. Thus a plant using 2 pounds of coal of 7,000 B. t. u. heat value may be as efficient as one using only 1 pound of coal of 14,000 B. t. u. An estimate of the efficiencies of public utility power plants, computed by the method used by the United States Bureau of Mines, shows a wide range of variation in performance among states, partly related, no doubt, to differences in the size of plants and their variable efficiencies but also to the varying heat value of the coal used. Power plants in New York State, Michigan, and the District of Columbia had consumption of slightly more than 1 pound of coal per kilowatt-hour, including the coal equivalent of other fuels used, whereas North Dakota, in the lignite area, showed a comparable consumption of 3.63 pounds, Wyoming 3.14 pounds, and Colorado 2.26 pounds (table 7). Accordingly, it appears that maximum practical efficiency for the major proportion of plants is being approached, and further marked gains must await improvement in methods. The efficiency of central power stations appears already to be advancing at a slower rate, but, of course, depressed business conditions have retarded the introduction of new equipment, and a rise in activity may lead, for a time, to resumption of rapid gains in efficiency.

In 1919–20 steam railroads consumed 170 pounds of coal per 1,000 gross ton-miles of freight service and in 1937 only 117 pounds, a reduction of 31.2 percent.[24] An examination of data collected by the Interstate Commerce Commission by regions indicates that little, if any, of this reduction in consumption is attributable to a shift from lower grade to higher grade coal.

The quantity of coking coal consumed per ton of pig iron was reduced 18.9 percent from 1918 to 1936,[25] because of increased recovery of coke through the byproduct process and use of coke-oven gas and tar as fuels (fig. 26). Savings of fuel through recovery of gas, tar, light oils, and coke breeze, by the extension and improvement of byproduct coking in place of beehive ovens, likewise resulted in economies.

In general, promotion of fuel efficiency needs less attention from public organizations than reduction of wastes in mining and handling. Conservation in use is a question of reduction of expense or improvement of service for individual users, and therefore it is connected with the private-gain motive. Steady, although possibly slower, progress in this field seems assured.

Reduction of Energy Required for a Given Use

It is likely that a change in the direction of development is taking place. Whereas increasing mechanization for over a hundred years meant the application of

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[15] Cf. Arthur D. Little and R. V. Kleinschmidt, "Coal Consumption as Affected by Increased Efficiency and Other Factors," *Proceedings, Second International Conference on Bituminous Coal*, Pittsburgh, 1928, vol. 1, p. 112.

[16] *Ibid.*, pp. 112–13.

[17] *Ibid.*, p. 113.

[18] F. G. Tryon and H. O. Rogers, "Statistical Studies of Progress in Fuel Efficiency," *Transactions, Second World Power Conference*, Berlin, 1930, p. 362. For original presentation of data, see W. B. Heroy, "Tendencies of Power Production," *The Strategy of Minerals*, New York, 1919, ch. IV.

[19] *Ibid.*

[20] *Ibid.*, p. 361.

[21] *Ibid.*

[22] U. S. Bureau of Mines data.

[23] A. T. Shurick, "King Coal Still Rules 75 Percent of His Domain, Though Credited With But 54 Percent," *Annalist*, April 2, 1937, p. 517.

[24] *Minerals Yearbook, 1938*, p. 716.

[25] *Ibid.*

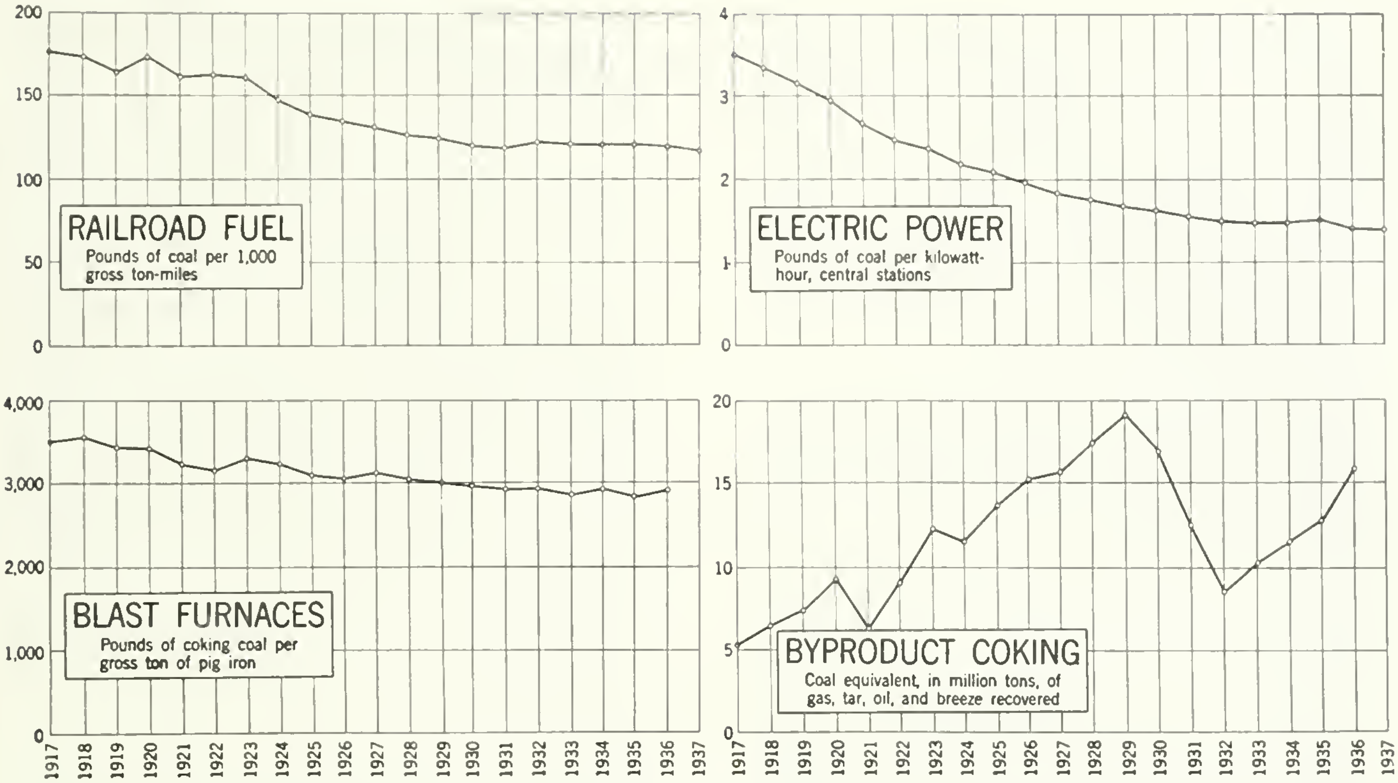

FIGURE 25.—Tendencies in Fuel Efficiency in the United States, 1917–37. (Reproduced from *Minerals Yearbook, 1938*, p. 716.)

TABLE 7.—*Fuel consumed in the generation of electrical energy for public use in selected States and the United States, 1937*

State	Coal, net tons	Fuel oil		Natural gas		Total coal equivalent (tons)	Energy production generated by fuel plants (excluding production by wood fuel), thousands of kilowatt-hours	Pounds of coal per kilowatt-hour
		Barrels	Coal equivalent (tons)[1]	Thousands of cubic feet	Coal equivalent (tons)[2]			
Massachusetts	1, 399, 530	307, 802	70, 488			1, 470, 018	2, 252, 494	1. 31
New York	4, 739, 735	360, 930	82, 655	4, 114, 419	168, 817	4, 991, 207	8, 448, 356	1. 18
Pennsylvania	6, 061, 711	34, 304	7, 856	3, 113, 341	127, 742	6, 197, 309	8, 428, 064	1. 47
Ohio	5, 502, 637	24, 402	5, 588	3, 738, 292	153, 384	5, 661, 609	8, 134, 972	1. 39
Illinois	5, 909, 881	48, 471	11, 100	3, 732, 724	153, 156	6, 074, 137	7, 797, 086	1. 56
Michigan	2, 418, 700	48, 978	11, 216			2, 429, 916	4, 487, 898	1. 08
Wisconsin	1, 142, 925	53, 073	12, 154			1, 155, 079	1, 781, 971	1. 30
North Dakota	349, 633	24, 449	5, 599	219, 454	9, 004	364, 236	200, 431	3. 63
Maryland	444, 122	16, 415	3, 759	114	5	447, 886	650, 408	1. 38
District of Columbia	370, 452					370, 452	681, 862	1. 09
Virginia	852, 210	29, 976	6, 865			859, 075	1, 211, 994	1. 42
West Virginia	1, 912, 371	921	211	61, 624	2, 528	1, 915, 110	2, 467, 017	1. 55
North Carolina	278, 858	22, 392	5, 128			283, 986	414, 054	1. 37
South Carolina	123, 705	7, 169	1, 642			125, 347	132, 259	1. 90
Kentucky	651, 084	8, 383	1, 920			653, 004	580, 244	2. 25
Wyoming	120, 378	8, 472	1, 940	429, 387	17, 618	139, 936	89, 133	3. 14
Colorado	493, 448	38, 881	8, 904	424, 527	17, 419	519, 771	459, 508	2. 26
Utah	164, 551	5, 527	1, 266	1, 738	71	165, 888	213, 719	1. 55
Other States	9, 401, 693	13, 063, 711	2, 991, 666	154, 731, 023	6, 348, 604	18, 742, 053	25, 477, 275	1. 47
Total, United States	42, 337, 624	14, 104, 256	3, 229, 957	170, 566, 643	6, 998, 438	52, 566, 019	73, 908, 745	1. 42

[1] 4.3667 barrels of oil=1 ton of coal.

[2] 24.3721 thousand cubic feet of gas=1 ton of coal.

Source of basic data: Federal Power Commission, *Electric Power Statistics, 1937*, pp. 10, 11, 19–24; National Bituminous Coal Commission, *Bituminous Coal Tables, 1936-37*, p. 46.

more energy, now less energy is often needed because of a streamline type of operation. This contrast is shown, for example, in modern smooth-running continuous rolling mills in the steel industry against the former cumbersome mills. The amount of dead weight requiring energy is still very large. Transportation of one person weighing perhaps 150 pounds in an automobile weighing 3,000 pounds consumes necessarily an enormous input of energy for the effective work done. Somewhat similar conditions have existed in railroad transportation and are now being improved by new light-weight trains.

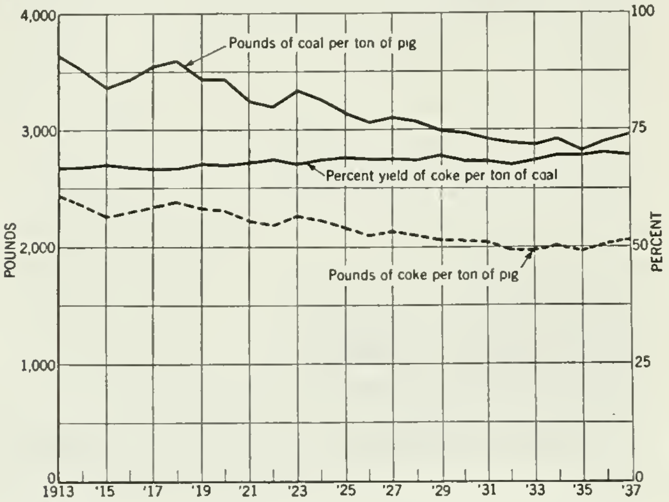

FIGURE 26.—Pounds of Blast-Furnace Coke Consumed Per Gross Ton of Pig Iron, 1913–17. (Reproduced from *Minerals Yearbook, 1938*, p. 788.)

One of the great modern needs is for more extensive and better use of insulation materials to eliminate the enormous waste of heat energy in most branches of utilization. It is physically possible by thorough insulation to reduce the requirements of energy for space heating, as in residences, to a small fraction of tnat now required. Although possibilities of conservation of mechanical energy appear less promising as far as reduction of effective work is concerned, new methods designed to short-circuit the intermediate step of conversion of a fuel to heat energy before mechanical energy is derived may some day be made practicable. Direct conversion from fuel to mechanical energy is the aim of the "fuel cell."[26] This process, in a promising experimental stage, effects direct transformation of coal gas into electrical energy by a chemical change analogous to that of discharging a storage battery.[27] Methods of such revolutionary character suggest great potentialities for further conservation in use.

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[26] H. C. Howard, "The Fuel Cell," mimeographed release issued by the Coal Research Laboratory, Carnegie Institute of Technology, Pittsburgh, 1932.

[27] Arthur E. Morgan, "The Planned Use of Water Resources," *Third World Power Conference*, Washington, 1936, sec. V, Paper No. 13, p. 10.

CHAPTER 5.—STABILIZATION AND SOCIAL CONTROL OF THE COAL INDUSTRY

The Problem of Social Control

The coal industry in the United States has suffered a depression since the early 1920's. The all-time peak of production was established in 1918. During the period of business prosperity from 1923 to 1929, the condition of this industry was in marked contrast to that of industry in general. Annual production of coal during the period was maintained at a level above 550 million tons, but the industry operated at a loss because of rapidly decreasing sales realization. In 1920 the average realization at the mine on bituminous coal was $3.75 per ton. In 1929, the last year in which bituminous coal production exceeded 500 million tons, the average price was only $1.78, or 47 percent of the 1920 value. During the general business depression since 1929 the coal situation has grown worse. Production has fallen off decidedly, accompanied by a further decrease in price.

Although many factors have contributed to the depressed condition of the industry, principal responsibility for the critical situation may be ascribed to lack of adaptation of the industry to a market in which the trend is no longer upward but, in fact, seems to be downward at a rapid rate. It has become evident that the demand and potential supply of coal are out of adjustment and that the internal structure of the industry is badly shaken by destructive competition, which has tended to introduce not only inefficiency in operation, but also wasteful utilization of resources.

It is true that there has been some decline in the demand for coal owing to increased use of fuel oil, natural gas, and water power and because of economies made possible by the increasing technical efficiency of coal utilization. Despite the decreasing and fluctuating demand, however, capacity has been maintained at a high level by interdistrict competition, with the result of unstable prices and, until recent years, of unstable wage structures accompanied by labor strife and hardship, and inconvenience to producers and consumers.

When the importance of coal to the economic and social welfare of the country is considered, it is evident that some steps should be taken to return the industry to a stable and profitable basis. Coal is the world's most important source of energy, and the United States is fortunate in owning an abundant share of this resource. The country's manufacturing and transportation industries are for the most part dependent on coal as a source of power. The number of men directly employed by the coal industry runs into hundreds of thousands. At its lowest point in recent years, the industry employed more than a half million men. In addition, a million and a half or more persons dependent on the wages of coal miners must be considered, as must persons dependent on wages from industries that could not operate without coal.

The philosophy of government in the United States in general is against governmental intervention in private enterprise. The condition of the coal industry is such, however, that operators, miners, and the general public have felt the need of regulation. There are some persons, of course, who oppose, as a matter of fixed policy, any form of regulation, and there are also those who favor complete nationalization. This divergence of attitude, where it is based on rational grounds, is an indication of the presence of effective arguments both for and against regulation. There is no absolute standard by which the question of regulation of the coal industry may be judged. The final decision rests on numerous factors relating to the efficiency of enterprise in the industry, return received by those attached to the industry, the exhaustibility of coal and other energy resources, and the importance of energy to the general welfare. Mining of coal by private industry in the United States must be credited with a high degree of practical effectiveness, considering the scatter and variability of reserves, and repeated losses of investment suffered since 1922. The driving force of desire for economy and profitable operation applied to abundant reserves has provided a plentiful supply of low-cost fuel. Enterprise has been relatively free from the uncertainty of shifting political trends. On the other hand, the record with regard to conservation, standards of living for miners, and fair rates of return for enterprise leaves much to be desired. There is little basis for supposing that corrective tendencies will develop without some overt action to control practices that the industry heretofore has been unable to remedy.

Public responsibility in the coal industry exists, not only because of the need for improvement in the industry, but also because stability and avoidance of excessive loss are essential to conservation and rational use. Little progress in the reduction of waste may be expected if production must be pursued under conditions of prolonged loss and bankruptcy. It is inevitable that harassed enterprise will seek a way out by ruthless exploitation or by building its own defense mechanism of control. The aim of regulation, therefore, is not coercive interference with those engaged in coal production, but rather to create a framework of public policy within which enterprise may function efficiently, a framework which maintains a balance among the interests of operators, miners, and consumers of coal.

Attempts to Control the Industry

In the past, industrial control of the coal industry has arisen from the industry, labor organizations, local governments, States, and the Federal Government.[1] Until 1932 control was largely incidental to other objectives. Taxes levied by State and local governments controlled to some extent the functioning of the coal industry. In the main, taxes have been levied against reserves; consequently, they have encouraged extension of mining to provide revenue for payment of the taxes. On the other hand, such taxes have tended to prevent high capitalization of coal lands, which in turn has tended to reduce royalty payments and to permit new companies to enter production without large expenditure for reserves. State legislation has been applied to such elements as accident prevention, compensation, mine inspection, reporting of production and reserves, property rights (such as leaving of barrier pillars at boundaries), use of explosives, and intrastate transportation of coal.

Control by the industry has been in the nature of informal or formal voluntary agreements, or understandings. Trade associations, organized locally in major producing areas, and also nationally, have been a means of dissemination of information and of determination of policies. Likewise, there have been some cooperative marketing associations with agency powers. The McAlester Coal & Fuel Co., in Oklahoma, which became an exclusive selling agency for certain large operators in 1904, represents an early attempt at such cooperation,[2] whereas Appalachian Coals, Inc., organized in 1932 among producers in southern West Virginia, Virginia, eastern Kentucky, and northeastern Tennessee, represents a later and much more extensive attempt.[3] The Bituminous Coal Act of 1937 encourages the formation of such cooperative agencies. By the middle of November 1938, there were nine applications before the National Bituminous Coal Commission.

For at least 40 years, collective bargaining for wage rates has attempted stabilization of interdistrict competition in the coal industry. Wages usually constitute more than 60 percent of the production cost, and therefore they have a major effect on pricing. As early as

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[1] For a summary of numerous proposals, see L. E. Young, "Proposals for Stabilization of the Bituminous Coal Industry," *Proceedings, Third International Conference on Bituminous Coal,* Pittsburgh, 1931, vol. I, pp. 53–81.

[2] Frederick Lynne Ryan, *The Rehabilitation of Oklahoma Coal Mining Communities,* University of Oklahoma Press, Norman, 1935, p. 58.

[3] J. P. Williams, Jr., "Organization of the Production, Processing, and Distribution of Coal and Coal Products," *Third World Power Conference,* Washington, 1936, sec. II, Paper No. 4, (conference proof) p. 8.

1898 wage rates were fixed on a coordinated competitive basis by means of a collective interstate agreement covering most of the mines of the central competitive field—those in western Pennsylvania, Ohio, Indiana, and Illinois.[4] The advantages of this method of standardizing wage rates and costs over large competitive areas were recognized by numerous operators and mine workers. As early as 1906, nevertheless, difficulty in negotiating collective wage agreements began to be encountered because of the pressure on wage standards exerted by competition from operators whose wage rates were not stabilized by the union agreements.[5] This pressure resulted in several extensive suspensions during the pre-war years. During and immediately after the war, mines enrolled under the collective agreements increased in number until, in 1922, 70 percent of the bituminous-coal mines were operating under such agreements. The general coal strike in 1922, however, broke the strength of the union in the southern fields. The union continued to be strong in the northern fields, and wage rates in those fields were maintained at peak levels. The Jacksonville agreement, signed in February 1924, projected the previously determined wage rates for 3 years additional. Northern mines, being burdened with relatively higher wage costs, lost business to the southern mines. Numerous northern mines closed and reopened on a nonunion basis, but the reestablishment of competitive relationships was not sufficiently rapid to prevent marked expansion of capacity in the southern fields. By the early part of 1925 most of the operators in northern West Virginia had broken away from the union contract.[6] On expiration of the agreement, March 1, 1927, a strike ensued in the northern fields which terminated in almost complete abandonment of interstate collective bargaining. The business depression after 1929 so weakened the union that it became less effective than it had been since about 1890. An unprecedented rehabilitation occurred in 1933 and 1934 under the National Recovery Administration, and some additional gains have been registered in the subsequent period. At present, all but about 2 percent of the miners are covered by union agreements.

This history of unionization indicates the weakness of attempts to stabilize interdistrict competition and pricing solely through the medium of collective bargaining on an interstate basis. Mines able to maintain a nonunion status usually have a decided advantage over those which operate under a union agreement. There are always some operators who ply this advantage to the limit and who eventually force other operators to use strenuous measures to defend their competitive position. The result is strife, bloodshed, and bitterness, not because of a desire on the part of most operators to use oppression, but because such tactics become the only means of survival of enterprise. In the end, unionization becomes an inadequate stabilizing force and may even aggravate the instability existing otherwise, as it did in the period from 1922 to 1927. Unionization under governmental sponsorship may yield a more effective control, although practically it is almost impossible to place all operators on an equal footing with respect to wage-rate levels. Lack of representation of consumer interests and possible continuation of cutthroat competition are further objections. It must be recognized that no group has a monopoly on remedies; on the contrary, an equitable representation of all interests is essential to balanced development.

Widespread demands for Federal intervention in the coal industry were made before the World War. The Bureau of Mines, for example, was created largely because of popular remorse at a disastrous mine explosion in 1907. Thousands of pages of congressional hearings have been taken from time to time on various phases of the coal industry. In 1913 more than 2,000 pages of testimony were taken in Senate hearings on conditions in the Paint Creek district of West Virginia.[7] Congressional hearings were held in 1914 on conditions in the coal mines of Colorado; in 1917 on coal-price regulation; in the same year and in 1918 on the causes of shortages of coal; in 1919 and 1920 on price increases; in 1920 and 1921 on coal transportation; in 1921 on labor conditions in the coal fields of West Virginia, the appointment of a Federal Coal Commissioner, the publication of information regarding ownership, production, distribution, costs, sales, and profits in the coal industry, and to declare coal production and distribution charged with public interest; in 1921 on wages and working conditions; in 1926 on proposed coal legislation; in 1928 on conditions in the coal fields of Pennsylvania, West Virginia, and Ohio; in 1929 on a bill to regulate interstate and foreign commerce in bituminous coal, provide for consolidations, mergers, and cooperative marketing, require the licensing of coal-mining companies, and create a bituminous coal commission; in 1932 on similar bills. Federal coal acts passed in 1935 and 1937 were both preceded by extensive hearings.

During the World War, the Federal Government ventured into the actual regulation of the coal industry. Under the Food and Fuel Control Act (the so-called Lever Act, passed August 10, 1917) the

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[4] Supreme Court of the United States, *Brief for Government Officers, respondents in No. 636 and petitioners in No. 651* (*Carter Coal* Case), October Term, 1935, p. 41.

[5] *Ibid.*, p. 41.

[6] *Ibid.*, p. 49.

[7] *Ibid.*, p. 15.

President was given authority to fix coal prices, control production, distribution, and storage of coal, and to establish a monopoly of purchase, sale, and distribution of coal. The United States Fuel Administration was created to handle the administration of the fuel provisions of the act. The objective of the act was not stabilization of the industry, but establishment of reasonable prices and control of the coal supply incident to the prosecution of the war. Nevertheless, experience in the problem of regulation of the coal industry was gained. Some of this experience has been valuable in indicating the possibilities and shortcomings of Federal regulation, particularly with regard to relationships developed between the industry and the regulatory body, and with regard to the problem of administration involved in enforcing compliance with provisions intended to yield only generalized control rather than intervention in the detailed managerial problems of coal production.

Experience in Other Nations

Regulation of coal in the United States is by no means without parallel among the nations of the world. Quite the contrary, regulation of some sort, much of it more drastic than that introduced in the United States, has been introduced in every major coal-producing country and in nearly all minor producing countries as well.[8]

The bulk of the world's coal, of course, is produced in the United States and Europe. In 1936 the United States produced 34.4 percent of the world output of coal, Great Britain 18.1 percent, and Germany, including the Saar, 16.1 percent.[9] These three countries combined accounted for 67.7 percent of the world total. The Soviet Union produced 8.7 percent and France 3.6 percent. The five leaders, as a group, mined 80.0 percent, or four out of five tons, of all coal produced.

In Great Britain, the second largest producer, control of the industry is based on Part 1 of the Coal Mines Act of 1930, as amended. The control includes regulation and facilitation of market sharing, centralized selling, and price maintenance.[10] Germany has evolved regulation of the coal industry through the cartel system, and, of course, the tendency has been toward strict regimentation under the totalitarian regime. State-owned mines in 1934 produced 17 percent of the coal.[11] In the same year all the coal from the Saar and 80 percent of that from Lower Saxony came from state mines. Control of coal mining in Russia is far different from that in Germany, even though strict control is a part of each program. Whereas most of the production in Germany is under a governmentally regimented private system, that in Russia is under state-owned properties operated as state trusts. Coal reserves in France are part of the public domain. They have been given as "concessions" in perpetuity by the state under the basic law of 1810.[12] The law of 1919 provides for the making of new concessions for a 99-year period. The concessions are bought and sold substantially the same as other property. Governmental regulation in France provides for fixing of maximum prices of coal, quota limitations for imports of coal, zoning of the market, amalgamations for marketing, and agreements with foreign mines for the maintenance of reasonable price levels.

Japan controls the coal industry under a cartel system similar to that of Germany.[13] Nearly all the coal reserves in Holland are owned by the state, which produces about 70 percent of the coal taken from domestic mines. In Norway all production and shipment of coal is handled by private enterprise, but the Norwegian Government has made extensive loans to the private companies. Coal production and coal prices in the Union of South Africa are not regulated by the Government; nevertheless, grading of the coal is required and safety provisions are imposed. The Czechoslovakian Government, in the period before its demise, owned some mines which accounted for 6.5 percent of the bituminous coal and 16 percent of the lignite production. Laws regulating mining provided that beds thinner than 45 centimeters (about 18 inches) could be left standing only with permission of the authorities, and top beds were required to be worked before those underneath. Conservation of coal resources has reached an advanced stage in Hungary, where reserves are small; although there are no cartels, the Government fixes prices for lump coal. Seven to eight percent of the Hungarian coal production is from state mines. In Bulgaria the Government has taken over most of the coal mining, and state-owned mines produce 80 percent of the total.

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[8] A discussion of social control measures for coal adopted in Europe is presented by Lewis L. Lorwin and Arthur Wubnig in pt. four, sec. IV, ch. 2, this volume.

[9] Report of the International Labour Office, *Technical Tripartite Meeting of the Coal-Mining Industry*, Geneva, May 1938, "Part 1, Economic Conditions," p. 54. In the data, lignite is converted to equivalent coal units.

[10] Mines Department, Great Britain, "Organization of the Production and Distribution of Coal," *Third World Power Conference*, Washington, 1936, sec. II, Paper No. 4–A, (conference proof) pp. 4–8. Also George W. Strasser, *The Effects upon Operating Efficiency of the British Experiment in Production Control in the Coal Industry*, National Resources Committee, Washington, January 15, 1936.

[11] J. E. G. Knepper, "Organization of the Production, Processing, and Distribution of German Coal and Coal Products," *Third World Power Conference*, Washington, 1936, sec. II, Paper No. 4, pt. 1, (conference proof) p. 12.

[12] H. de Peyerimhoff, "Organization of Coal Production and Distribution in France," *Third World Power Conference*, Washington, 1936, sec. II, Paper No. 4, (conference proof) p. 3.

[13] For information on regulation in countries not ranked among the first five in production, see various papers presented at the Third World Power Conference, Washington, 1936.

Thus a reconnaissance of foreign efforts at regulation of the coal industry reveals a variety of methods, but regulation is a part of nearly all the programs, and highly developed systems are found among the leading coal-producing countries. A significant portion of the coal production in foreign countries is from state-owned mines, and additional quantities are mined from state-owned reserves leased to private companies.

Factors Involved in Public Policy toward the Coal Industry in the United States

Foreign experience in control of the coal industry does not indicate an inevitable course in the United States, but it is useful in showing problems and possibilities.

Where a nonrenewable resource is absolutely essential to maintenance of the customary standard of livelihood, public interest is certain to be aroused by wastefulness and poor coordination of production. Industry in the United States is founded on the wide application of technical processes energized by an abundant power supply. Exhaustion, or even growing scarcity, will have serious consequences. Those who condone wasteful and inefficient practices often contend that technicians somehow will solve the problem of shortage. The real question, however, is whether the best possible solution is found. Every technical process is only a means for utilizing resources already available in a somewhat concentrated form. Coal, as an extremely concentrated source of energy, holds high promise for technical advance in utilization.

The prospects of the energy supply are regarded in a pessimistic light in many quarters. This pessimism is warranted only if a policy of wastefulness and poor utilization is sanctioned. Under rational use of coal, the possibilities for future advancement are almost boundless.

From the standpoint of conservation alone the case is clear; government ownership and operation of coal mines could enforce the highest attainable standards of extraction. If necessary, cost considerations could be disregarded to permit mining of the last ton of coal in the mine, an action analogous to the disregard of costs by the Postal Department in maintaining service for out-of-the-way places to promote national unity and development. On the other side is the fact that an intricate system of rights to coal reserves has been developed. Traditions and existing circumstances are the starting point for future policy. The transition from private development of coal reserves to nationalization would require a complete reconstruction. The price to be paid for the best reserves would make them dear indeed, whereas it does not appear desirable as a general policy to make government a dumping ground for resources not wanted privately. A further consideration is that coal reserves not yielding a current income are not a social burden, but, should they be purchased publicly with interest-bearing bonds, they would become a fixed charge.

Were coal reserves in the United States sufficient for only a few decades, the argument for nationalization would be reinforced. In fact, scarcity of reserves is the chief supporting argument in the British plan of nationalization recently adopted. In the United States a somewhat parallel situation exists only in the Pennsylvania anthracite region[14] and in a few of the older bituminous coal fields. In most of the bituminous coal and lignite areas, however, there is no urgent need for such drastic action.

An Integrated Policy

Public interest in coal is focused on two major problems: (1) balanced utilization of coal resources, and (2) minimization of waste. Regulation of the coal industry is not itself an ultimate goal. It is an overhead item whose existence is warranted only because of faulty coordination of enterprise. The objective is to maintain the highest degree of freedom of utilization of coal reserves, subject only to restraints needed to guard valid social claims. The degree of control necessary depends on the record of the industry with regard to operating performance and conservation of reserves and on the scale of effect of the increasing depletion of reserves. Anyone who has carefully studied the coal industry must be impressed by the complex mixture of accomplishments and shortcomings existing in the past. To envisage the future as one of harmony and achievement under a simple plan of either regulation or nonregulation is grossly to oversimplify the problem.

In the coal industry there is a place for private, regional, and national action. It is desirable to retain the initiative and driving force of private enterprise in the coal industry, but enterprisers must realize that they are exercising a stewardship over irreplaceable resources of vital interest to the general welfare. And government must be concerned with the serious task of directing such operation in socially useful ways. Insofar as actions are subject to the checks of competing sources of energy, regulation cannot have a free hand.

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[14] The Anthracite Coal Industry Commission in Pennsylvania believes that purchase of surplus anthracite reserves would be profitable to the State. See Commonwealth of Pennsylvania, *Report of the Anthracite Coal Industry Commission*, Harrisburg, July 30, 1938, p. 12.

A coal-pricing policy, for example, may encourage greater use of oil and gas, perhaps wastefully, to the extent that coal production will decline drastically, thereby bringing disruption and unemployment to the industry. The coal industry has not functioned well, but it is not on the road to extinction. The prospects are, instead, that it will recuperate as soon as oil and gas reserves begin to fall short of meeting the demand. When this shortage will occur depends on discoveries of oil and gas and on their rate of use. All current information points to exhaustion of oil and gas long before coal reserves are depleted. An integrated program requires that utilization of energy take into account the relative scarcity of reserves. In this connection, danger exists, not only of a short-lived boom in oil and gas consumption followed by a painful reversal, but also of an over-rapid depletion of the best and most accessible coal reserves. Policies, both private and public, therefore, should work in the direction of greater concentration on those portions of the coal reserves that are most abundant.

In addition to interfuel competition, there is regional competition within the coal industry itself. The effect of this regional competition is to defeat almost any State action that imposes on the industry a standard of performance not counterbalanced in competing States. Advantages inhere, nevertheless, in certain forms of decentralized public control—advantages such as simplified administration, closer contacts, and specialized skill. In the past States have exercised some control over the coal industry. In general the functions retained at the present time may continue to be handled by the States. Mapping of reserves of coal, coordination of mine workings, prevention of flagrant forms of waste, education on local details of conservation, research adapted to local needs of coal resources, inspection of mines, procedures for the settlement of conflicts between the operator and the surface-land owner, especially where exaggerated claims have been the rule, are functions that States may perform.

The broad features of a program of conservation and rational utilization must be administered by the Federal Government for the reason that coal is a national problem. Coal is shipped without regard to State or local boundaries; consequently, a necessity exists for unified action to prevent regional inequalities. Pricing, trade practices, coordination of production and consumption, information on production and marketing, labor relationships, wage standards, social security, safety standards, stabilization, interfuel competition, relationships to transportation, foreign trade, strategic development with regard to national defense, and concerted attack on wastage of reserves demand Federal attention. All these factors have come before the Federal Government, and in some of them a considerable measure of regulation, already has been introduced.

A broad-gauged approach to control of the coal industry under Federal auspices was attempted under the National Industrial Recovery Act passed in June 1933.[15] Codes established under the act were required to comply with the provisions of the act, but otherwise they were privately determined. Although the codes were privately administered, they had the force of law in so far as they rested on Federal authority to regulate the industry. Codes were adopted, not only for bituminous coal and anthracite production, but also for associated industries such as the retail solid fuel industry, wholesale coal industry, coal dock industry, coal mine loading machine industry, coal cutting machine industry, and mine car manufacturing industry. The codes remained in force until the act was declared unconstitutional by the Supreme Court in May 1935. This semigovernmental regulation was succeeded by a more direct Federal regulation under the Bituminous Coal Conservation Act of 1935 passed in August of that year. The act was in force only until May 1936, when it too was invalidated by the Supreme Court. Currently the industry is operating under the act passed in April 1937, entitled the "Bituminous Coal Act of 1937."

The Federal Government has undertaken to bring order to the bituminous coal industry largely through the medium of minimum prices. The concept and circumstances of regulation of the industry should not be confused with those involved in regulation attempted elsewhere. In many respects the principles applied under the Coal Act of 1937 are unique. It is an error to assume that the features of public utility regulation apply with full force, or that the competitive idea is forsaken. Whereas public utilities are seldom competitive within the service provided and the areas served, coal companies are competitive with regard to both features. The idea of a fair return on a fair value of property applied to public utilities is inapplicable under the Coal Act. The act does not purport to guarantee a satisfactory return for every enterprise. It is intended to guarantee an even break to a company with average costs in each large designated area. It merely places a floor below which the average level of prices is not permitted to fall. In an industry that is not expanding, it is not necessary to reinvest earnings to finance extensions or to attract outside capital beyond the amount taken out of the industry. Royalties and depreciation are allowed under the act as part of the cost of operation. Separation of reserves of coal from the operating companies accordingly will increase the allowable cost. Actually some outside capital will be drawn to the industry, especially by companies whose costs are below the average. And some investment loss will be taken directly or through recapitalization of high-cost companies.

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[15] A detailed discussion of recent regulation of the coal industry is presented in pt. four, sec. IV, ch. 1, this volume.

Full measure of competition applies above the minimum level of prices for coal. As long as this competition exists eagerness to attract business by price cutting will persist. An operator has the privilege of selling coal in competition with any other producer in the United States at or above the prescribed minimum price.

The cost principle of minimum-price regulation has little chance of success if it is applied to individual concerns. The Coal Act does provide for this type of regulation. Minimum prices are not a "cost-plus contract" for individual producers. They are intended to set minimum levels applicable to all companies, high-cost and low-cost producers alike, in each minimum-price area. Thus there are rewards for improvement of efficiency by individual companies.

Some variation of costs with the business cycle will exist. Better utilization of capacity will distribute fixed costs (those that must be met irrespective of output) over a larger tonnage and therefore reduce the average cost per ton on which the minimum prices are based. Industries with large fixed costs find that costs per unit vary inversely with output. Fortunately costs in the coal industry do not show this inverse variation. Wages, outlays for supplies, royalties, selling expenses, expenditure for mine power, and even allowances for depreciation and depletion vary almost in proportion to output. Wages are usually at least 60 percent of the total cost, and the other variable items probably bring the total variable costs to 80 or 90 percent of all costs. Moreover, the cyclical fluctuation in prices on items of purchase will act as a stabilizer of unit costs, or it may actually lead to lowering costs in depression and raising them in prosperity. In general it appears that the average-cost principle is a feasible basis for regulation of the coal industry, although it may be inapplicable to other industries.

Should costs in the coal industry be found to fluctuate too much to provide a stable basis for minimum prices, an average over a period of years may need to be used. In this event variations in unit costs resulting from changes in the operating rate may need to be differentiated from variations resulting from alteration of wage rates and prices for power, supplies, equipment, and other items of expenditure. These are factors that will require observation under actual experience.

In the regulation of any industry there is the question of evasion and short-circuiting. Numerous well-intended plans have been shattered on this rock. Secret transactions, underclassification, and overweighting are some of the devices used. Such tactics are difficult to apply in the coal industry for the reason that most of the coal is shipped by common carrier and many of the wage rates also are based directly on tonnage. Irregularities in records should be relatively easy to detect.

The Federal program for regulation of the bituminous coal industry presents numerous favorable aspects. The chief unfavorable feature is the gigantic size of the administrative problem until preliminary procedures are completed. Because of this problem, further burdens should not be imposed immediately. Progress toward an integrated energy-resources policy, however, should continue as rapidly as the regulatory machinery will permit.

CHAPTER 6.—PROPOSALS FOR COAL CONSERVATION

Promotion of conservation and rational utilization of coal is important because (1) coal is a basic necessity for production of power, heat, and thousands of commodities using carbon either in nearly pure form or in combination with other elements and (2) resources of coal are nonrenewable. That the pace of industry in the United States has been accelerated to a higher rate than in other countries is undoubtedly due in no small degree to the enormous bonus of coal reserves favorably situated for extraction and transportation to the major consuming centers. These reserves need to be guarded. But conservation does not connote preservation by prohibiting the use of coal for current needs; it means, instead, getting maximum results from what is available—more units of useful work from every ton of reserves. Wastes may or may not be avoidable, and unanimity of opinion on the degree of avoidability cannot be attained. Those who find wasteful production or wasteful use profitable are not likely to be advocates of conservation, even though the waste be detrimental to the interests of the Nation as a whole. On the other hand, it is improper to assume that a practical standard of operation can reach theoretical perfection in conservation. Any program of action must take into account at the outset existing conditions in the industry and existing means for utilization as well as available means for direction and control. These factors have been reviewed in preceding chapters. In the present chapter, suggestions bearing on general questions of policy are brought together.

Authority for Regulation

Coal resources, it should be observed, are distributed among 31 States, and coal consumption takes place in every State as well as in coastwise and foreign trade. In the past, coal operators and State and local governments have shown a singular inability to deal with problems of disorganization and waste in the industry. In general, too many elements are beyond the reach of these organizations to enable them to take constructive action. There is also insufficient incentive for cooperation through the medium of State compacts. In the main, coal is a national problem, and therefore the only public body capable of coping with the problem is the Federal Government.

Several aspects of the power of the Federal Government might bear on regulation of the coal industry. The interstate commerce provision of the Constitution applies at least to all coal shipped in interstate channels. About 3 out of every 4 tons produced enter directly into interstate commerce, or they are used as fuel by railroads subject to the jurisdiction of the Interstate Commerce Commission. Moreover, Supreme Court decisions in 1937 and 1938 have followed the Minnesota, the Shreveport, and the Wisconsin case decisions,[1] originally applied to railroads, as a basis for extending to business generally, Federal jurisdiction over intrastate commerce when such commerce burdens or obstructs interstate commerce. It seems clear that these rulings apply in so far as coal is an item of trade, but some importance also attaches to the fact that coal enters into the production and transportation of products which in turn are items of trade among the States or with foreign countries.

Second, Federal jurisdiction arises from the power to provide for the common defense. World powers today are all large consumers of coal. World War experiences indicated the critical significance of coal in such national emergencies. Besides this direct applicability in emergencies, there is the further fact that common defense in actuality is also a matter of long-term improvement and maintenance of industrial strength. Coal plays an important part in the high productivity needed to uphold the position of the United States.

Third, the Federal taxing power may be used, within limits, to effect better operation and conservation. A refundable tax of 19½ percent on bituminous coal is included in the Bituminous Coal Act of 1937. The tariff also has been applied as a measure of control, although all imports of bituminous coal have been admitted duty-free in 1935 and subsequent years.[2] Part of the anthracite and coke imports, however, have been subject to the tariff.

Fourth, the rule of reasonableness enunciated by the Supreme Court in 1911 in cases involving the Sherman Antitrust Act[3] was reaffirmed in the *Appalachian Coals* case,[4] decided in 1933. Subsequently, the idea of the degree of Federal interest has been introduced.[5] This late shift in the trend of decisions very likely indicates broadening of the rule of reasonableness in the direction of enabling the Federal Government to take more positive action. Democratic government by nature requires a degree of freedom to accommodate legislation to the general welfare. Provision for the general welfare seems to have been accepted as a matter of course when the Constitution was drafted, being written into the preamble as an objective of the entire plan. But difficulties to be encountered in application of the idea were not fully anticipated. Since 1789 the Nation has undergone a transformation from youth to maturity. Superabundance in resources has been supplanted at many points by threatening inadequacies. The problem of conquering vast undeveloped areas has gradually given way to that of conservation of resources already possessed, resources subject to the unremitting approach of depletion and ultimate exhaustion. Irreplaceable coal reserves, which supply more than half the total energy resources, affect the general welfare with more than ordinary force. It should be emphasized that exhaustion of coal resources will not be a convulsive development. Accordingly, the need for continuous adaptation of public policy is obvious. The need also is urgent, owing to inability to rectify damages after they have occurred. Injury of irreparable character is a weighty factor in legal decisions, particularly in injunction suits, and such injury to coal reserves is a matter of concern not only to particular groups but to the entire Nation.

In general, there appears to be little reason to believe that the jurisdiction of the Federal Government is much, if any, short of that required for direction and control commensurate with national dependence on coal production and use. The existence of permissive power, however, does not settle the question of what should be done. Steps actually taken should arise out of genuine needs. Suggestions for a coordinated

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[1] Respectively 230 U. S. 352 (1912), 234 U. S. 342 (1914), and 257 U. S. 563 (1922).

[2] Special statement prepared for this study by the United States Tariff Commission.

[3] *Standard Oil Co. of New Jersey* v. *U. S.*, 221 U. S. 1 (1911) ; *U. S.* v. *American Tobacco Co.*, 221 U. S. 106 (1911). See also *U. S.* v. *U. S. Steel Corporation*, 251 U. S. 417 (1920).

[4] *Appalachian Coals, Inc.*, v. *U. S.*, 288 U. S. 344 (1933).

[5] *Jones and Laughlin* case, 301 U. S. 37 (1937) ; *Consolidated Edison* case, 83 Law Ed. 131 (1938).

Federal policy determined from a study of the coal industry are presented herewith.

Provision of Adequate Information

The first requirement for the development of a rational coal policy is availability of reliable and adequate information for the formation of judgments. There should be no lowering of the high standards established in the past, especially in 1917, 1918, 1923, 1929, and 1936. Indeed, it is desirable to have better data on price fluctuations, types of equipment used in mining, depth and thickness of workings, waste prevention, earnings of coal companies, new openings and abandonment of mines, and irregularity of operations among individual mines. Since the usefulness of the information is determined largely by how generally it is made available, adequate provision should be made for tabulation and publication. Curtailment of the publication fund—a small item beside the cost of obtaining and assembling the information—is particularly to be avoided.

Coal is only one source of energy, and the formulation of a comprehensive energies policy must take into account all forms of energy available. Consequently, it is important to have at hand information bearing not only on coal but also on other forms of energy. It is recommended, therefore, that information on energy resources be consolidated more than it has heretofore. It appears desirable to consolidate into a single "Energy Resources Yearbook," prepared under the supervision of a central committee, information collected by various governmental agencies such as the Bureau of Mines, National Bituminous Coal Commission, Geological Survey, Bureau of the Census, Bureau of Foreign and Domestic Commerce, Bureau of Labor Statistics, Petroleum Conservation Division of the Department of the Interior, Tariff Commission, Interstate Commerce Commission, Bureau of Standards, Federal Trade Commission, and Federal Power Commission. The volume should contain information on coal, petroleum and natural gas (and their derivatives), synthetic fuels, and water power, and probably also on electric power and other forms of utilization. Such a compilation would go a long way toward focusing attention on a coordinated policy. For many years, the Geological Survey and the Bureau of Mines have distinguished in their annual reports between metals and nonmetals. The distinction between energy resources (including water power) and inorganic minerals is advisable, not only from the standpoint of the energies problem, but also from that of "nonenergy" organic and inorganic uses.

Continuous education of producers on the best industrial practices and of the public on the problem of energy resources is essential to progress in the development of a more enlightened policy. Emphasis should be placed on the saving (less trackage, haulage, and reserves) involved in more thorough mining. Periodic reports of the progress of conservation would create a keener awareness of the problem. States may be helpful in drawing attention to regional considerations.

Administrative Machinery for the Promotion of Conservation by Both Private and Public Means

Waste of coal resources cannot be prevented so long as conditions of chaotic operation exist in the industry. Government ownership and operation could, by fiat action, introduce drastic conservation measures. This solution seems simple and obvious, but those who advocate nationalization of the coal industry underestimate the practical difficulty of taking over millions of acres of coal lands, hundreds of thousands of leases, and thousands of operations, as well as of establishing an organization that could function efficiently in the infinitely variable conditions existing in coal mining. The balance of the argument is against nationalization.

Some operators have advocated Government ownership of submarginal coal reserves, the reserves to be leased to private operators when the coal is needed. The difficulty with this plan is that it would place on the Government a heavy burden of debt against property that would not be useful for perhaps many decades. It would make Government the dumping ground for reserves of questionable worth, and it would tend to frustrate conservation by encouraging operators to keep the best reserves and to concentrate even more than at present on mining them. Government purchase may well be considered, however, in connection with other desirable land programs such as prevention of soil erosion, reforestation, development of parks, and control of stream flow.

Since mining of coal by private enterprise is favored, a prerequisite for the promotion of conservation is the establishment of stability in the coal industry. It is believed, however, that the coal industry, working alone, cannot accomplish much toward elimination of waste, for the reason that conservation will be subordinated to the desire for more profitable operation. The Federal Government, therefore, must take the initiative to orient the industry toward methods that conserve the deposits. Experience gained under the N. R. A. and the Coal Acts of 1935 and 1937 should be utilized as fully as possible. The National Bituminous Coal Commission, established under the 1937 act, is the logical organization to assume major responsibility for conservation and rational utilization. The need for cooperation of the Commission with other Federal organizations, however, is apparent. Work on technical research should remain with such organizations as the Bureau of Mines and the Geological Survey, which have spent years of time in developing competent personnel. Likewise, owing to interrelations between coal mining and transportation, close cooperation between the Coal Commission and the Interstate Commerce Commission is necessary for mutual consideration of problems.

The present Coal Act does not extend to lignite, defined as coal of less than 7,600 B. t. u. per pound or of more than 30 percent moisture. Economically, lignite should be subject to the same regulation as coal of higher rank. Lignite is not markedly different from subbituminous coal, declared to be covered by the act. As long as only small amounts of lignite are mined, of course, serious problems are not likely to arise. It is important, however, to extend the usefulness of lignite to aid in the conservation of higher rank fuels.

The most desirable relationship of the Federal Government to the anthracite industry is not so easily determined. About 95 percent of the anthracite, including semianthracite, occurs in eastern Pennsylvania. Unlike bituminous coal, the area of occurrence is very compact and entirely within the bounds of a single State. Anthracite is mainly a high-grade residential fuel, whereas bituminous coal is used predominantly for industrial purposes. An advanced stage of depletion also has been reached, the anthracite reserves being about one-fourth consumed or lost. Mining is unusually difficult and wastage is high. Illegal ("bootleg") production is peculiar to the anthracite industry. In recent years, total output of anthracite has been only half as much as it was in the peak years during the World War. In general, the industry is more in need of regulation than is the bituminous coal industry. But it has been an orphan as far as public responsibility is concerned. Neither the States nor the Federal Government have taken the initiative to introduce controls such as those adopted for the bituminous coal industry.

The small amount of anthracite outside Pennsylvania need not be treated as a special case. Its regulation should be brought within the scope of the National Bituminous Coal Commission, which would then be termed more properly the National Coal Commission.

The Pennsylvania Anthracite Coal Industry Commission has recommended that the State consider future purchase of excess anthracite reserves in Pennsylvania, the reserves to be worked later by private companies under a leasing arrangement.[6] The feasibility of such a plan depends chiefly on the price to be paid for the reserves. Because of compactness of the area, single ownership could do much to conserve the resources by promoting unified development of mining. It is not a matter of great moment whether the reserves are owned by the State or by the Federal Government, if the plan is to pay for the reserves out of royalties or by a tax on the industry. Federal ownership would probably effect some saving of interest cost. In regulation of the marketing of the anthracite, the State is almost helpless unless monopolistic control of the market is allowed to continue. There is, of course, the competition of the illegal producers and of other classes of fuels, particularly fuel oil, gas, coke, and high-grade bituminous coal. Undoubtedly a considerable share of the blame for the present plight of the anthracite industry is attributable to monopolistic or quasi-monopolistic attempts in the past to maintain prices at untenable levels. Much of the damage is already done, but especial care should be taken to avoid further disruption. In the event of failure of the State to act, the need for conservation of anthracite indicates that the Federal Government should assume responsibility. The task should be handled by a single coal commission for all classes of coal.

Finally, the entire program for coal needs to be coordinated with that for oil, natural gas, and water power. For this purpose, a voluntary association of regulatory bodies is inadequate. Conflicts of interest are inevitable, and, accordingly, a central organization requires some power of enforcement to be effective.

Waste in Coal Production and Preparation

Thus far, the best approach to coal conservation in the United States has been made through the leasing system in effect for coal on the public domain. Operating regulations for lands leased to private concerns provide minimum standards for waste, safety, and management of mines.[7] It is suggested that these regulations be made the basis for development of future public policy on coal conservation.

The Bituminous Coal Act of 1937 is not directly a conservation measure. The Coal Commission is empowered to study the problem, but otherwise elimination of waste is entirely optional under the act. This omission of any provision for at least minimum standards of conservation is considered a serious weakness. It is believed that the Federal Government should initiate minimum requirements for at least the easily applied methods of conservation. A reasonable expectation would be that the Coal Commission actively foster conservation as a major interest and compel all operators, perhaps under license, to submit mine plans and accurate maps (required in some States) in order that suggestions could be made for better methods of mining and for unified development of fields and so that, in the event of abandonment, a record would be available to aid in future planning and reduction of waste. Stricter enforcement of mine safety laws would eliminate much of the haphazard, wasteful mining.

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[6] Commonwealth of Pennsylvania, *Report of the Anthracite Coal Industry Commission*, Harrisburg, Pa., July 30, 1938, pp. 12–13.

[7] U. S. Department of the Interior, *Operating Regulations to Govern Coal-Mining Methods and the Safety and Welfare of Miners on Leased Lands on the Public Domain, Under the Act of February 25, 1920, and Amendments thereto*, second edition, 1938.

In general, coal operators should be given as much freedom in operation as can be allowed without hampering the program for elimination of waste. In the production of coal, perplexing operating problems are encountered, and regulation of details by a central agency is likely to result in lost motion. There are, nevertheless, certain features of the industry that require concerted action, and operators left to themselves cannot be expected to achieve the necessary cooperation.

Conservation does not mean strangulation of the industry for the sake of the future but rather teamwork to accomplish what students of the problem agree is a desirable goal. On the average, costs of reasonable conservation measures are not exorbitant. Some measures will immediately yield more than they cost. Fifteen to twenty cents per ton average additional cost, if wholly applied to better mining and preparation, could reduce waste to one-half or one-third its present extent.

The time to begin conservation is in the early stages of development, when rich resources are available. This is the reason immediate action should be taken to prevent the most flagrant wastes. Destruction of commercially minable beds by removal of coal in underlying beds should be prohibited. A mining company should be required either to mine all the coal of a designated minimum thickness or to leave the coal in a condition suitable for future recovery. Encouragement should be given to the development of machines for mining thin beds. Abandonment should be allowed only by special permit, after a thorough check has been made of the condition of the reserves to enable appropriate action to be taken for their preservation.

The evidence is inconclusive whether subsidization or a tax refund system is advisable. It has been observed earlier that the greatest gains in conservation would accrue from extraction of coal pillars, panels, and stumps left in the mine. In some instances this removal could be undertaken without a change in the system of mining; in others, introduction of a different system, such as the longwall system, would be necessary for practically complete recovery. It is not known how extensively coal operators will adopt these methods voluntarily, given a greater degree of stability such as that contemplated under the 1937 Coal Act, nor is it known how generally new methods can be applied. Perhaps a small tax should be levied with the provision of a refund to companies complying with minimum standards of recovery. In this way the cost of conservation would be distributed. The problem needs further study to determine whether the method can be applied uniformly and without danger of discrimination.

Coal production shows a considerable seasonal variation. Present wage agreements call for a 7-hour day and a 5-day week, but the amount of lost time is large. It may be found advisable to permit some overtime work on a regular basis during the active season of the year. Idle facilities would thereby be reduced, and operations would be more highly concentrated. Both of these features would aid in conservation and stabilization.

With the introduction of a short workday and workweek, a new condition has also arisen in which the mine and the equipment are utilized a smaller part of the time, even when the regular schedule is followed. Coal companies, therefore, are forced to shoulder a heavier overhead than they did previously, and workings are more widely scattered and more difficult to administer. Multiple-shift mining should be applied more extensively than it has been in the past.[8] It is possible, under present hours, to introduce a dual shift without operating far into the night and, therefore, without greatly disrupting community life.

Wastes in Processing

Although most of the wastes in coking have been eliminated by the use of efficient byproduct ovens, there is still some waste resulting from the production of coke in beehive ovens. There may arise in the future a serious problem of wastes in processing, if low-temperature carbonization and gasification are extended or if production of liquid fuels from coal is introduced. Change of the form of fuel, particularly to a liquid state, is effected only with heavy loss of potential heat value.

At the present time byproducts yielded by the coking process are available in surplus, and, therefore, there is a tendency to waste them. The development of a better market for byproducts would be helpful in eliminating these wastes.

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[8] For a study of multiple-shift mining, see Albert L. Toenges and Robert L. Anderson, *Multiple-Shift Mechanical Mining in Some Bituminous Coal Mines*, U. S. Bureau of Mines Information Circular 7014, May 1938.

Wastes in Consumption

Economical methods of coal utilization have gone a long way toward conserving coal reserves. Economy in use is usually directly remunerative to the consumer; accordingly, coal-saving methods are being developed by private industry, although the average efficiency for all steam-generating plants is well below the maximum attained by the best; also the average thermal efficiency of kilns, heating and melting furnaces, and other uses of heat in treating products is low.

In some branches of consumption, notably residential use, wasteful methods predominate. Since smoke indicates waste, the murkiness of urban areas attests inefficiency in the use of coal. Automatic stokers are now sufficiently developed to eliminate most of the smoke emitted. Pulverized-coal combustion likewise permits almost smokeless operation, although satisfactory methods for preventing the fine ash from going up the chimney have not been perfected. Use of coke or anthracite where coal firing produces smoke will solve the problem. Perhaps when all costs—extra cleaning bills, detriment to health and property, and low efficiency in combustion—are considered, smoke abatement is socially profitable.

Coordination of Coal Production and Distribution

In terms of actual cost, transportation of coal is, on the average, about as important as production of coal. The implication of this importance is obvious; regulation of coal mining covers only half the problem with regard to pricing and the dynamics of the market. The United States Coal Commission in 1923 reported inequities in freight rates, particularly in the long- and short-haul relationships. The rate structure has added to the disruption of the industry by leading to abandonment in some areas at the same time that additional excess capacity has been added in other areas. Owing to the fact that only limited readjustment of freight-rate differentials has taken place since 1923, the findings of the Commission on this question remain applicable.

Likewise the conclusion of the Commission that marketing of coal was inefficient is applicable now. Cooperative marketing through Appalachian Coals, Inc., and other similar agencies may be somewhat helpful, but the agencies are primarily for private price control. By means of subagency contracts with member companies, the marketing organization is usually left substantially the same as it was before. More attention needs to be focused on reduction of marketing cost and on making marketing a means of regularizing production.

The Federal Government's dealing with foreign trade in coal is deemed satisfactory, especially with the recent adjustments made under the reciprocal trade agreements. There are some persons who contend that the Nation should attempt to remedy the ills of the coal industry by expanding exports and curbing imports. This plan, unless accompanied by an expanded import balance in other commodities, involves the illogical reasoning that traffic can be kept going in one direction even if none of it is allowed to return. At best, gains would be bought at a sacrifice of our own resources.

Interfuel Policy

Coal, oil, natural gas, and water power are keenly competitive in certain ranges of the market, and a considerable measure of indirect competition also exists. In general, it should be a matter of consumer choice to decide what type of fuel is most desirable for his particular use. On the other hand, it must be realized that conditions arise in the market that are not conducive to the best utilization of fuel resources. Mineral fuels are often produced in superabundance, even though the total quantity of reserves be sufficient to last only a few years. The pattern of fuel-resource utilization needs to be examined with a view to establishing a better relationship between current utilization and total resources available. Wherever fuels may be readily substituted, the Government should foster use of fuel available in more abundance for fuel available in less abundance. Water power is available substantially in perpetuity. Coal ranks next in terms of abundance, whereas oil and gas, according to present knowledge, are relatively much less abundant than coal. Accordingly, there is a need to foster the use of water power wherever the cost of development is favorable.

On the other hand, the life of the oil and gas resources is being threatened by consumption for uses that could be about as well served by coal. The chief direct inroads into the market for coal are being made by the use of fuel oil for space heating and large stationary installations for power production, and the use of natural gas for heavy-duty industrial purposes. This utilization should be discouraged as much as possible by a program of education, but it appears, also, that additional steps need to be taken. Regulation of pipe lines by the Federal Government with a view to establishing a quantity rate for transportation similar to that charged coal shippers by railroads (a tonnage rate) seems to be desirable. A tax on fuel oil, high enough to discourage further extension in consumption but, at the same time, not too high to cause severe hardship to present consumers, would be a step toward rational utilization.

Part of the responsibility for the inroads of oil and gas lies with the coal industry. Exceptionally high prices for coal during and after the World War invited the use of substitute fuels. In this connection, it should be observed that increases in per-ton wage and other costs without similar increases for competing fuels shift consumption away from coal. The dilemma of high rates and short working time cannot be solved by a further increase in costs. Average hourly earnings of miners are above those of most other industries, but average working time is shorter.[9] Constructive action for raising the standard of living should be in the direction of regularization of work and improvement of environment, rather than toward raising the ratio of coal costs to costs of competing fuels.

Technological progress has also favored a shift to oil and gas. The best defense against this shift is acceleration of the technology of coal consumption. Government and private industry should relentlessly pursue technical research in coal. There is at present a need for a general study of the common uses of coal to determine what factors divert consumers' choice to other fuels, often despite higher costs. Millions of dollars have been spent on the study of liquefaction and gasification of coal, but the greatest gains have been made in the simpler adaptations to use, such as byproduct coking, pulverization, sizing, cleaning, and automatic stoking. Coal promises to remain a heavy-duty fuel. In this type of use, a comparatively direct consumption is essential to keep costs at a minimum.

The Nation's long-run total energy requirements are increasing. This upward trend, however, does not mean that larger quantities of coal will be required. Technological improvements in utilization which enable coal to compete with substitute fuels reduce the tonnage needed. On the other hand, lack of such improvements also results in contraction as long as substitute fuels are available at a competitive price. The coal industry, therefore, cannot proceed on the assumption that there will be an expansion to remedy the ills. Increasing mechanization of mines is reducing labor requirements to such an extent that the industry cannot absorb unemployed miners without incurring a burden that will further discourage the use of coal. As a general rule, it is better to attempt an equitable distribution of the gains of efficiency than to minister to special needs by stifling progress. Regulation does not automatically assure desirable consequences. The kind of action taken is the decisive factor. Whatever measures of regulation are adopted, it is important that there be continuous self-criticism and constructive investigation of methods and administration.

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[9] See U. S. Bureau of Labor Statistics, *Monthly Labor Review*, November 1938, pp. 1165–1174, and similar information in other issues.

PART ONE—SECTION II
THE PETROLEUM AND NATURAL GAS INDUSTRIES

CHAPTER 1.—THE ECONOMIC SIGNIFICANCE OF OIL AND GAS

By Glenn E. McLaughlin[*]

Comparative Sources of Energy

During the past 100 years or so there have been three significant shifts in the sources of energy. In the first place, there was a change from nonfuel energy to mechanical energy. This shift took the form of a change from the use of wind, water power, and draft animals to the use of coal, oil, and gas. The latter forms of mineral fuels have been used as indirect sources of energy; that is, they have been made to do work by driving machinery. In fact, until the middle of the nineteenth century, most transportation on land was by horse or by carriage, and most transportation on water was by wind-driven ships. Moreover, in agriculture most of the power was supplied by draft animals, and in manufacturing the use of water power exceeded power supplied by steam engines until about 1870.[1] The second significant shift relates to the change in source of fuel used for heating purposes. Wood was supplanted by coal, and more recently there has been some tendency for coal to be supplanted by fuel oil and natural gas. The third shift has been a general and significant shift among the mineral sources of energy from coal to oil and gas, both as a means of driving machinery and as a source of heat. In 1899 bituminous and anthracite coal accounted for 89.1 percent of the total energy contributed by mineral fuels and water power in the United States.[2] In that year oil and gas accounted for 7.7 percent of the total—4.5 percent for petroleum and 3.2 percent for natural gas. The rise in the use of petroleum and natural gas has been much greater than the growth and annual supply of total energy. In 1937 both crude petroleum and natural gas reached a peak of relative importance. Together they accounted for 42.8 percent of the energy total—32.4 percent for petroleum and 10.4 percent for natural gas.[3] In the meantime, the relative importance of coal had dropped until in 1937 it accounted for 53.7 percent of the total. Much of this change has represented a shift from coal to oil and gas, especially since 1926. In that year the grand total energy supply in the United States was 24,415 trillion British thermal units. In 1937 the total was about the same—24,183 trillion. During this 13-year period, however, the relative importance of oil and gas rose from 26.2 percent to 42.2 percent.

Changes in Major Petroleum Products

In the early history of the petroleum industry its main products were kerosene (or coal oil) and crude lubricants. Kerosene was used both for lighting and as a fuel, especially for cooking. Somewhat later, natural gas was saved and used as an illuminant. Kerosene remained the major product of the petroleum industry until about 1910, when gasoline became most important. In volume of production, however, gas oil and fuel oil for many years exceeded gasoline, mainly because refining technique did not permit greater yields of motor fuel. With increasing use of cracking processes during the post-war decade, the production of gasoline finally, in 1930, exceeded that of all fuel oil—distillate and residual. Although gasoline remains the major product of the oil industry, in recent years the demand for distillate fuel oil, both as a heating fuel and as a fuel for internal combustion engines, has been growing more rapidly than the demand for gasoline. On the whole, it may be said that the great growth of the petroleum industry during the twentieth century has been related primarily to the expansion of motor-fuel demand.

Importance to Consuming Industries

The great economic importance of petroleum results from its use in transportation industries and, primarily, of course, in the operation of motor vehicles. The entire motor transport is dependent on petroleum products, and it has been estimated that for all the methods of transportation approximately 60 percent of the power requirements are supplied either by gasoline or by fuel oil.[4] The importance of oil and gas in the transport industries stems also from the widespread use of residual fuel oil and Diesel oil by steamships and railroad locomotives, and the use of gasoline for airplanes and motorboats. Of ocean-going vessels of the United States merchant marine, about 93 percent of the total tonnage at the end of 1937 was moved by oil, used either in Diesel motors or as fuel under boilers.[5]

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[*] Bureau of Business Research, University of Pittsburgh. Some of the illustrations which are presented in this section represent preliminary charts from a forthcoming report entitled, "Technology and Labor Requirements in Petroleum and Natural Gas Production," by O. E. Kiessling, H. O. Rogers, G. R. Hopkins, and others, now in preparation as a cooperative study by the U. S. Bureau of Mines and the W. P. A.-National Research Project. These charts have been made available to the National Resources Committee through the courtesy of J. W. Finch and David Weintraub, directors, respectively, of the cooperating agencies indicated. They can be distinguished from the other illustrations which are included by the credit lines acknowledging their source as given above. The reader should note that the graphs are subject to revision and that the data on which they are based will be published in the cooperative report referred to.

[1] In the year ended May 31, 1870, prime movers in manufacturing and hand and neighborhood industries consisted of steam engines of 1,215,711 horsepower and water wheels of 1,130,431 horsepower. U. S. Bureau of the Census, *Manufactures: 1919, General Report and Analytical Tables*, p. 122.

[2] United States Bureau of Mines, *Minerals Yearbook, 1937*, p. 810. This percentage is computed with water power converted to fuel equivalents at *prevailing* central station practice.

[3] *Minerals Yearbook, 1938*, p. 704. These are preliminary percentages.

Furthermore, of the total installed horsepower—including automobiles and other mobile power units—in the United States in 1929 about 86 percent was dependent on petroleum products as a source of energy. If all motor vehicles except trucks, busses, and taxis be excluded, nearly 49 percent of the remaining horsepower is accounted for by internal-combustion engines.[6] Yet, automotive motors are in operation much less of the time than other prime movers. For example, in 1935 the available horsepower of motor vehicles was about 20 times that of electric-generating stations, whereas the estimated energy output in kilowatt-hours was 87 billion for automobiles and 92 billion for central electric stations.[7] Of total power actually produced, perhaps as much as 50 percent depends on petroleum for fuel.

Extremely important in economic growth has been the production of lubricants from petroleum. A plentiful supply of lubricating oils has been a major prerequisite for mechanical development, especially of heavy high-speed machinery. As yet there is no material other than petroleum that will yield lubricants in quantities sufficient to meet transportation and manufacturing demands.

In manufacturing industries, oil and gas are consumed mainly in petroleum refining, in iron and steel production, and in carbon-black manufacture. In many other industries products of petroleum are of considerable importance, notably in the construction and maintenance of highways, in the chemical industries, and for both domestic and industrial heating purposes.

The Effect of the Petroleum Industry on the Location of Manufacturing Industries

The older energy industries have exercised a direct influence on the location of manufacturing establishments. In early New England, for example, many factories used wood as a source of energy and were located not far from forests. Somewhat later, textile mills, as well as small machine plants, were located ordinarily on sites at waterfalls, where water power could be used to drive machinery within the plant. In the nineteenth century many of Pennsylvania's blast furnaces burned charcoal and were located directly within the great forests in the west central part of the State.

Coal, because of its high thermal value and the size of its reserves, has exerted a far greater influence on the location of industry. In particular, the iron and steel industry and the making of heavy machinery have been located with reference to supplies of coal. In fact, the present industrial importance of the northeastern section of the United States is based in large measure on the bituminous reserves of Pennsylvania and nearby States.

Oil and gas, on the other hand, have attracted to themselves comparatively little manufacturing activity. Aside from carbon black, smelting, and glass, no other important industry has located in or near natural-gas fields, and in recent years, the tendency has been for smelters and glass factories to locate with respect to raw materials and obtain gas by pipe line.

Major manufacturing establishments located in oil-producing sections of the country have been petroleum refineries. Even refineries, however, do not move from field to field but draw on more distant sources for fuel or raw materials when those near at hand have become depleted. Thus many oil districts have attracted comparatively few refineries, except those needed to supply motor fuel for local or regional needs. Oklahoma, for example, although a heavy producer of crude oil, has never accounted for a comparable share of the Nation's refining activity. Gasoline, the main refined product, is consumed all over the country, but especially in areas of dense population. Crude has moved toward the major market for motor fuel and fuel oils—at least toward the market as far as cost of transportation was concerned. In other words, petroleum refineries have not as a rule been located simply in oil fields but, for the most part, have been situated within reach of seacoasts or within heavy consuming areas. The feasibility of transporting gasoline by pipe line within the past few years, coupled with greater yields of gasoline from cracking, has modified this relationship somewhat and facilitated the operation of petroleum refineries in the midcontinent field.

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[4] Myron W. Watkins, *Oil: Stabilization or Conservation?* (New York, 1937), p. 3.

[5] United States Maritime Commission, Division of Research, *Semi-Annual Report, No. 1100*, p. 1.

[6] C. R. Daugherty, "Horsepower Equipment in the United States," *American Economic Review*, September 1933, p. 439.

[7] A. A. Potter, "The Production of Power," *Technological Trends and National Policy*, National Resources Committee, 1937, p. 252.

For manufacturing industries generally, the oil and gas fields have exerted little influence on location. Most of the industries which now consume oil and gas have been located with respect to other considerations, and, as a matter of fact, many of them already had been established in relationship to supplies of coal or other sources of energy. The development of petroleum products came too late to determine the initial location of the industries which consume those products, and so far the use of petroleum has not led to a shift in the centers of production of those industries. The low cost at which crude oil, natural gas, and their refined products could be transported lessened the attracting power of oil and gas. It has proved simpler to move oil and gas to the market than to shift industries to these sources of fuel. Moreover, the production of crude petroleum may shift rather rapidly, since total output often begins to decline soon after a new oil field is opened. In fact, field output may start declining after a few months, and the per-well average usually drops from the beginning. For these reasons oil and gas districts have never attracted the great variety of miscellaneous manufacturing industries which characterizes the older energy-producing districts of the industrial Northeast.

Texas now leads all other States in the value of mineral production, having outranked Pennsylvania in 1935. Yet the value of manufactured products in Texas remains a fraction of that in Pennsylvania. In Pennsylvania a much larger proportion of the mineral production mined within the State is consumed by local industries. This difference can be accounted for principally by the fact that the manufacturing industries constitute one of the major markets for bituminous coal, whereas the leading markets for petroleum products are the transportation industries. These latter industries naturally are located with reference to sources of traffic and not sources of fuel.

Since the main consumers of petroleum products are motor vehicles, not industrial plants, and since fuel oil can be transported from the Gulf coast to the North Atlantic seaboard at low cost, it can hardly be expected that the oil-producing States will develop as major manufacturing areas. Indeed, there is little evidence that the center of manufacturing activity in the United States has moved westward as a result of the shift in source of energy from coal in the Northeast to oil in the Southwest. If anything, the availability of low-cost petroleum fuels at Atlantic seaports has strengthened the locational advantage of the seaboard for manufacturing industries. This is not to deny, however, that there has been a considerable industrial development in parts of Texas, California, and other oil-producing districts.

Growth of the Petroleum Industry

The American petroleum industry was initiated with the drilling of the Drake well in Pennsylvania in 1859. Production of crude petroleum in the following year is estimated at 500,000 barrels. Since that time production of crude oil has grown with a high degree of regularity until, in 1929, it amounted to 1 billion barrels. Production then fell to approximately three quarter billion barrels in 1932 and recovered to an all-time peak of slightly more than 1¼ billion barrels in 1937. Up to the beginning of 1900 the total output of the industry approximated 1 billion barrels. During the following 22 years production amounted to approximately 5 billion barrels. The activity of the industry was further speeded up during the 1920's and 1930's, so that in the 16 years ended January 1, 1938, production approximated 14 billion barrels. Of the total output cumulated to the beginning of 1938 of 20 billion barrels, 70 percent was produced during the years 1922–37. The petroleum industry is one of the largest American industries. Judged by gross annual income, it exceeds any other branch of industry with the exception of agriculture. On the basis of capital investment or net income, it ranks somewhat lower.[8]

There are two important reasons for the rapid growth of the petroleum industry, both related to the use of the motor vehicle. In the first place, there has been a great shift of passenger traffic from the railroad to the automobile. In the second place, there has been a marked increase in the extent of travel and in the movement of goods. Indeed, the growth of the petroleum industry since 1900 has been closely coordinated with the growth in automobile registrations, and since 1910 the history of the petroleum industry may be roughly characterized as a search for more and more gasoline. In recent years the consumption of gasoline, and to a large extent the production of crude oil, has been closely coordinated, year by year, with changes in automobile registrations. The rapid expansion in the use of gasoline is roughly indicated by the jump in motor vehicle registrations from 8,000 in 1900 to 468,500 in 1910, then to 9,231,900 in 1920. The rate of growth slowed down somewhat dur-

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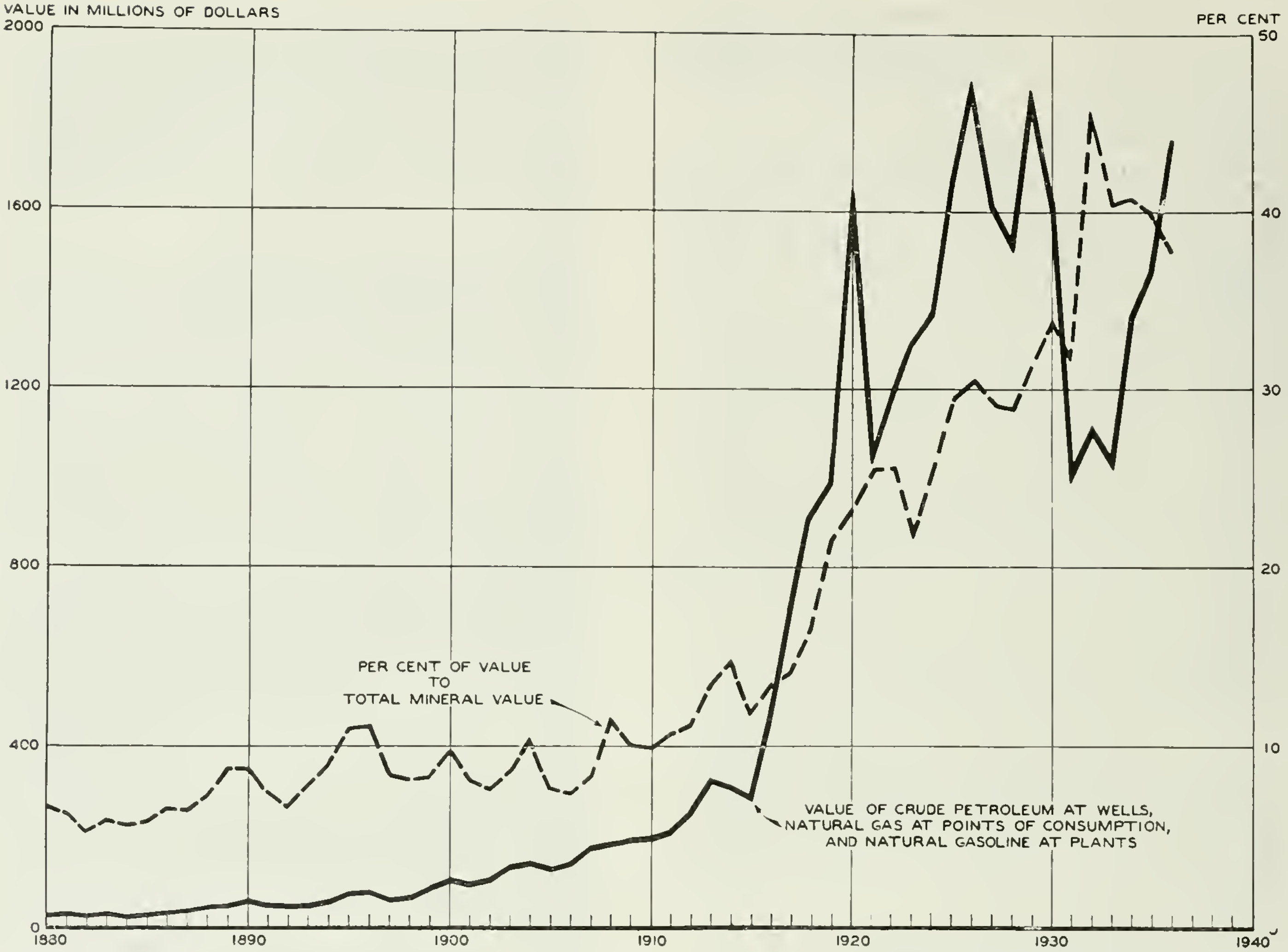
[8] Watkins, *op. cit.*, p. 7.



Hopkins and Dumbros
U. S. Bureau of Mines

Mineral Technology and Output Per Man Studies
W. P. A.—National Research Project

FIGURE 1.—Value of Crude Petroleum, Natural Gas, and Natural Gasoline, 1880–1936.

ing the twenties, but the number of motor vehicle registrations in 1930 amounted to 26,445,300. During the depression years the sales of new cars and trucks failed to equal the units that were withdrawn from use, so that registrations actually declined. By the end of 1938, however, the number of registrations had more than recovered the depression loss and stood at 29,212,000. The oil industry has kept up with the increase in demand for gasoline so successfully that the price of gasoline has tended to drop more rapidly than that of other wholesale prices since 1920. In part, and probably in major part, this has resulted from the technical developments in the production and refining of crude oil. To some extent, however, this continued search for larger supplies of fuel has been accompanied by excessive waste, both in crude oil and in natural gas, with the result that the amount produced has often had little relation to the current demand.

Scope of This Section

The purpose of this analysis is to obtain a clearer view of the proper relation of government to the oil and gas industry and to consider the basis of public interest in measures aimed at the conservation and prudent use of petroleum and natural gas. In order to indicate the size of the problem, attention is devoted to estimates of the amounts of oil remaining in the ground and to relative exhaustion of petroleum reserves. Improved methods of producing and refining crude oil are assessed in terms of their contribution to conservation. Emphasis is given to the greater efficiency that has developed in the use of oil and gas, particularly in its bearing on interfuel competition. The study should serve to indicate what conditions have been responsible for the waste of natural resources and capital in the oil and gas industry and to suggest various methods for restricting avoidable waste.

CHAPTER 2.—OIL AND GAS RESERVES AND THE PROBLEM OF RECOVERY

Extent and Character of Reserves

Definition of Proven Reserves

In a review of the estimates of oil and gas reserves attention must be given to a definition of what is meant by reserves and to a description of the methods by which the estimates of reserves are computed. Early attempts to set limits on the amount of oil and gas which was thought to be obtainable were usually made in terms of totals for the entire national domain, regardless of the extent of discovery. Soon, however, it became evident that such totals could be approximated with very little, if any, accuracy, and that they were, as one geologist expressed it, mere idle conjectures. More recently the estimates of oil and gas have been restricted to reserves in proven areas, where at least some production had been obtained. Moreover, the newer estimates have been stated in terms of the production recoverable by current methods; that is, proven reserves have been defined as that portion of the oil or gas underground in proven fields which can be economically brought to the surface and made available for utilization.[1] Many factors determine the extent to which oil and gas can be economically produced. For example, the price of oil or gas will determine the extent to which some wells can be operated, particularly wells which have long been in production. Among the other factors are the various technical methods of production, and in particular, the ways in which the reservoir energy is utilized to produce the crude petroleum. Obviously the improvement of various production methods has extended the amounts which could be included in recoverable proven reserves. In the determination of the oil which can be brought to the surface, perhaps the most important consideration is the present legal system under which oil and gas are produced—a system of separate ownership, often of small tracts of land on which each owner has the right to capture all the resources he can obtain from wells drilled on his property, regardless of whether the oil and gas are actually drained from under his own or adjacent tracts.[2] This legal system has resulted in competitive development of oil fields and, consequently, in much greater costs than would apply if an oil field could be exploited according to the most efficient current engineering methods.

Petroleum geologists and engineers, in estimating reserves, have set the extent of recovery at about 25 percent. About 35 percent is the current average of estimates by authorities of the extent to which oil is actually brought to the surface for consumption.[3] For natural gas, on the other hand, the relative recovery is much higher; estimates of recovery of somewhat above 75 percent have been used in calculating reserves.[4] The relative recovery in natural gas, however, has probably improved sufficiently to raise this percentage to between 85 and 90 percent. Among individual fields there are noticeable differences in relative recovery, depending on reservoir conditions and field-production practices.

Therefore the proven reserves may be thought of as a known inventory of oil and gas stored underground which can be recovered and used. Reserve estimates give no consideration to the additional quantities of oil and gas which undoubtedly lie under large areas as yet untested or to the additional supplies which lie below the present producing strata and which will be discovered as the drilling depth is extended. Most geologists emphasize that reserves must be understood as running inventories of supply, that they convey the record as of a definite date, and that they must be revised periodically in the light of increased knowledge. Improvements in exploratory techniques are constantly reducing the amounts of reserves which can be discovered in the future.

Methods of Estimation

Although there are some unknown factors which have to be guessed, reserve estimates are nevertheless not mere conjectures. The geologist considers the available pertinent data, including capacity and nature of the reservoir, its depth, quality of oil or gas, and nature of the sand or rock formation. Much depends on the portion of the pore space which is filled with oil, the permeability of the strata, and the pressure.

Natural-gas reserves, with adequate data available, can be computed with considerable accuracy. Given the volume of the reservoir, the pressure, temperature, and compressibility of the gas, the quantity of gas may be determined by the "saturation" or "pore space" method. This method is particularly applicable to new fields. For older fields the "pressure-volume" or "pressure-decline" method is used. It is based on operating data at the beginning of the life of the reservoir and after any given amount of production.[5] Naturally more accurate estimates of a reserve are possible after more production data have been accumulated. Estimates of total reserves are somewhat less accurate because in the total are included many new fields for which production data are fragmentary. A high degree of accuracy, however, has been achieved in reserve estimates for individual pools.[6]

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[1] V. R. Garfias and R. V. Whetsel, "Proved Oil Reserves," *The Science of Petroleum*, London, 1938, I, 532–33; identical article published as "Proven Oil Reserves," *Transactions of the American Institute of Mining and Metallurgical Engineers (A. I. M. M. E.) Petroleum Development and Technology (Pet. Dev. Tech.), 1936*, pp. 211–13; also see V. R. Garfias, R. V. Whetsel, and J. W. Ristori, "World Consumption of Petroleum Products and Related Fuels," *A. I. M. M. E., Pet. Dev. Tech., 1938*, p. 308.

[2] See pp. 200–201 of this report.

[3] Garfias and Whetsel, *loc. cit.;* A. T. Schurick, "Determination of Probable Life of Oil Reserves by a Mathematical Principle," *Annalist*, November 5, 1937, p. 740. The American Petroleum Institute Committee of Eleven seems to have made their reserve estimate on a basis of a 25-percent recovery consistent with the average practice in 1925. Committee of Eleven, American Petroleum Institute, *American Petroleum Supply and Demand*, New York, 1925, pp. 101–2. Methods of conserving reservoir energy have raised this percentage somewhat since 1925; *American Petroleum Institute Quarterly*, April 1938 p. 13. Although average recovery is usually taken as about 25 percent, estimates have been made varying from 10 to 50 percent, depending largely on the nature of the reservoir; see various petroleum engineers and geologists, *Petroleum Investigation, 1934*, Hearings on H. Res. 441, 73d Cong., pp. 1218–26, especially tabulation of John R. Suman, vice president, Humble Oil & Refining Co., *ibid.*, p. 1221. Hale B. Soyster, of the United States Geological Survey, estimated in 1934 that between 25 and 35 percent of the oil in the ground could be recovered by production methods then known. He used this recovery factor in estimating the reserves as of January 1934, *ibid.*, p. 20.

[4] V. R. Garfias, *A. I. M. M. E., Pet. Dev. Tech., 1935*, p. 243.

For oil pools the method of estimating reserves until a few years ago consisted primarily of a projection of the production curves of fields or groups of fields.[7] In cases where the field was comparatively new, estimates were based upon core analyses and guesses of acreage involved. Although the projection of production curves was made by those familiar with local conditions, this method was not susceptible to a high degree of accuracy. For one thing, only the average expectation could be forecasted. Moreover, the decline curve method could not be applied to a field until the field had produced for some time. In addition, the method did not consider, directly at least, the influence of changes in production technique.[8]

When proration methods were introduced, the decline curve method obviously became inapplicable. The new production curve indicated simply the amount of oil or gas which a State regulatory body allowed to be produced. Consequently, new methods of estimating reserves were evolved. Of these, the first may be called the acre-foot method, since it was based primarily on the acreage of the field and the average thickness of oil-bearing strata. The relative amount of oil in the strata was approximated from analyses of cores taken from either producing or test wells. This method was applicable as soon as the limits of the field were determined.

A method which can be used when the limits of the producing zone have not been defined is the "material balance method"—an attempt to estimate the initial quantity of oil and gas in the reservoir by adding cumulative production at a given time to the estimated balance in the reservoir. The volumetric change is calculated by using analyses of the fluid obtained from bottom-hole samples, analyses of the liberated gases and oils, bottom-hole temperatures and pressures, and other changes in the properties of the oil and gas and in the operating conditions of the well. Moreover, the rise in the oil-water contact line as withdrawals are made (i. e., water encroachment) and the expansion or contraction of the gas-cap area, if any, is often taken into consideration.[9] In some circumstances a fairly satisfactory reserve estimate can be made from a projection of energy decline curves. Some petroleum engineers have maintained that, where reservoir reactions can be accurately measured, the prediction of the reserves are correct within a range of 10 percent.[10]

Many of the above remarks do not apply to the estimation of reserves in limestone reservoirs, which have gained in importance in the past 5 years. Among these reservoirs and even within the same reservoir there is a decided lack of uniformity.

Estimates for the Country

Prior to 1922 no effort was made in the estimation of oil reserves to separate known areas from undiscovered areas. The estimates, consequently, varied widely, because the territory in which oil might be discovered is a very large one.[11] Although the early estimates are based on meager data and on widely varying supposition, they are not altogether inconsistent with estimates made after 1921. The first estimate which drew a distinction between known fields and undiscovered fields was made by the United States Geological Survey with the cooperation of the American Association of Petroleum Geologists. This estimate listed 5 billion barrels of crude "in sight" as of January 1, 1922, and 4 billion barrels additional as "prospective and possible" (table 1).[12]

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[5] John W. Finch, "Natural Gas Reserves and Their Conservation," *American Gas Association Monthly*, December 1936, p. 433. "In applying the saturation method there may be uncertainties in determining the area of the structure or the thickness or porosity of producing formations; and in applying the "pressure-volume" method the effect of encroaching edge water in altering shape and size of the gas-filled space may not be accurately determinable. Uncertainties concerning solubility of gas in the oil and its liberation from the liquid as the pressure is lowered make estimated gas that is associated with oil difficult." See also E. L. Rawlins, "The Study of Gas Fields," *Natural Gas*, May 1930, pp. 26–29, 56–58, and accompanying bibliography.

[6] The problem of estimating natural gas reserves is complicated by the fact that approximately half of the natural gas is found in direct association with oil, so that the estimate of gas depends on the relative saturation of the oil and the way in which the crude oil is produced; see U. S. Bureau of Mines, "Conservation of Petroleum and Natural Gas," *Third World Power Conference*, Washington, 1936, sec. IV, Paper No. 12, p. 12.

[7] *Petroleum Investigation, 1934*, p. 1970; *American Petroleum Supply and Demand*, p. 60; W. A. Ver Wiebe, *The Science of Petroleum*, I, 68.

[8] M. Albertson, "Estimation of Developed Petroleum Reserves," *A. I. M. M. E., Pet. Dev. Tech., 1936*, pp. 14–15.

[9] D. L. Katz, "A Method of Estimating Oil and Gas Reserves," *A. I. M. M. E., Pet. Dev. Tech., 1936*, p. 18; R. L. Huntington, "Estimation of Oil and Gas Reserves," *Oil and Gas Journal*, October 15, 1936, p. 124; *Petroleum Investigations, 1934*, pp. 1215–1217; L. G. E. Bignell, "Characteristics of Oil Reservoirs Give Data on Reserves to be Recovered," *Oil and Gas Journal*, February 20, 1936, p. 36.

[10] Albertson, *loc. cit.*

[11] See pt. two, sec. I, ch. 2, fig. 8, of this report.

[12] *Ibid.*, p. 289.

TABLE 1.—*Estimates of proven recoverable reserves of crude petroleum in the United States, 1908–39*

Author	Millions of 42-gallon barrels	Year of estimate
David T. Day	[1] 8,015–22,515	1908
Ralph Arnold	[2] 5,700	1914
U. S. Geological Survey	[3] 7,500	1915
Wallace E. Pratt	[4] 1,000	1917
David White	[5] 6,700	1918
H. J. Wasson	[6] 7,534	1920
H. J. Wasson	[6] 7,676	1921
U. S. Geological Survey	[7] 9,150	1922
U. S. Geological Survey	[8] 5,000	1922
H. J. Wasson	[6] 8,004	1922
H. J. Wasson	[6] 8,247	1923
H. J. Wasson	[6] 8,315	1924
H. J. Wasson	[6] 8,401	1925
American Petroleum Institute Committee of Eleven	[9] 5,321	1925
Federal Oil Conservation Board	[10] 4,500	1926
H. J. Wasson	[6] 8,447	1926
H. J. Wasson	[6] 9,223	1927
H. J. Wasson	[6] 9,675	1928
H. J. Struth, *Oil Weekly*	[11] 7,704	1928
H. J. Wasson	[6] 10,710	1929
H. J. Struth, *Oil Weekly*	[11] 9,071	1929
Ralph Arnold and W. J. Kemnitzer	[12] 27,603	1929
H. J. Wasson	[6] 10,803	1930
H. J. Struth, *Oil Weekly*	[11] 9,199	1930
H. J. Wasson	[6] 13,905	1931
Wallace E. Pratt	[4] 10,000	1931
H. J. Struth, *Oil Weekly*	[11] 10,578	1931
Federal Oil Conservation Board	[13] 10,000	1932
H. J. Wasson	[6] 13,571	1932
Valentine Garfias	[14] 12,000	1933
H. J. Wasson	[6] 13,816	1933
Petroleum Administrative Board	[15] 10,638	1934
H. B. Soyster	[6] 13,360	1934
C. H. Wegemann, based on Pratt's rate	[16] 8,300	1934
American Petroleum Institute	[17] 13,250	1934
H. J. Wasson	[6] 13,410	1934
C. B. Ames	[18] 12,000	1934
Petroleum Administrative Board, revised	[15] 10,763	1935
American Petroleum Institute, revised in 1937	[19] 13,632	1935
American Petroleum Institute	[20] 12,177	1935
Valentine Garfias	[21] 13,000	1935
H. J. Wasson	[6] 13,202	1935
Alex W. McCoy	[22] 10,700	1935
E. W. Marland	[23] 13,000	1935
Campbell Osborn	[24] 15,000	1935
Warren L. Baker, *Oil Weekly*	[25] 12,992	1936
Joseph Pogue, based on Pratt	[26] 12,400	1936
Garfias and Whetsel	[27] 10,575	1936
Oil and Gas Journal	[28] 12,502	1936
H. J. Wasson	[6] 13,608	1936
American Petroleum Institute	[17] 13,063	1937
Oil and Gas Journal	[28] 12,502	1937
E. B. Swanson	[29] 15,000	1937
J. Elmer Thomas	[19] 15,000	1937
Walter A. Ver Wiebe	[30] 13,000	1937
H. J. Wasson	[6] 13,435	1937
American Petroleum Institute, revised	[17] 15,856	1937
Oil and Gas Journal, revised	[31] 12,905	1937
W. V. Howard	[32] 14,423	1938
American Petroleum Institute	[17] 15,507	1938
Oil and Gas Journal	[33] 13,489	1938
Alex W. McCoy	[34] 12,909	1938
W. J. Kemnitzer	[35] 18,982	1938
Alex W. McCoy	[36] 13,584	1938
Oil and Gas Journal, revised [37]	[37] 13,976	1938
Oil and Gas Journal [37]	[37] 14,352	1939
American Petroleum Institute [38]	[38] 17,348	1939
Garfias and Whetsel [39]	[39] 14,000	1939

NOTE.—Estimates are as of the first of the year except as indicated below. Prior to 1922, no effort was made to separate known fields from undiscovered fields; since 1922, estimates represent the amount of oil which may be extracted by present known methods from fields sufficiently drilled and explored to permit of reasonably accurate calculations.

Source:

[1] Committee of Eleven of the American Petroleum Institute, *American Petroleum Supply and Demand*, New York, 1925, p. 42.

[2] *Congressional Record* of H. Rep., 75th Cong., 1st sess., W. E. Disney, Mar. 10, 1937, p. 4273; also Committee of Eleven of American Petroleum Institute, *American Petroleum Supply and Demand*, New York, 1925, p. 44.

[3] *Petroleum Investigation, Hearings on H. Res. 441*, Washington, 1934, p. 1461.

[4] Wallace E. Pratt, "Industry must Drill 20,000 Wells Yearly," *Oil and Gas Journal*, July 16, 1931, p. 19.

[5] L. C. Snider and B. T. Brooks, "Probable Petroleum Shortage in the United States and Methods for its Alleviation," *Bulletin of the American Association of Petroleum Geologists*, vol. 20, No. 1, January 1936, p. 16.

[6] H. J. Wasson, "American Oil-Reserve Replenishment," *Transactions of the American Institute of Mining and Metallurgical Engineers, Petroleum Development and Technology, 1937*, p. 230, table 1. Estimates arrived at Jan. 1, 1937.

[7] Estimate is of total oil reserves—oil in sight as well as possible and prospective. See next footnote.

[8] *Petroleum Investigation, Hearings on H. Res. 441*, Washington, 1934, pp. 1072, 1080.

[9] Committee of Eleven of American Petroleum Institute, *American Petroleum Supply and Demand*, New York, 1925, p. 59.

[10] *Report of the Federal Oil Conservation Board, September 1926*, pt. I, Washington, 1936, p. 8. Probably estimated as of September 1926.

[11] H. J. Struth, "Who Said There Is Too Much Oil in Sight, Anyway?" *Oil Weekly*, Apr. 18, 1932, pp. 16–18.

[12] Ralph Arnold and William J. Kemnitzer, *Petroleum in the United States and Possessions*, New York, 1931, p. 51.

[13] *Report V of the Federal Oil Conservation Board*, Washington, 1932, p. 7.

[14] *Petroleum Investigation, Hearings on H. Res. 441*, Washington, 1934, p. 1076.

[15] Petroleum Administrative Board, *Report on the Cost of Producing Petroleum, December 1935*, U. S. Department of Interior, 1936, p. 133.

[16] C. H. Wegemann, "Decreasing Reserves and Increasing Prices," *Oil and Gas Journal*, July 12, 1934, p. 37.

[17] *American Petroleum Institute Quarterly*, April 1938, pp. 12, 13.

[18] Address by C. B. Ames before the Fourth Annual Economic Council for Engineers, Johnsonburg, N. J., Aug. 15, 1934. Reprinted in *Petroleum Investigation, Hearings on H. Res. 441*, Washington, 1934, p. 359. Estimate is probably as of August 1934.

[19] J. Elmer Thomas, "Estimates of Proved Reserves," *Oil and Gas Journal*, July 22, 1937, p. 23. Revised on Jan. 1, 1937, to approximate what must have been in the known fields—based on later knowledge.

[20] U. S. Bureau of Mines, "Conservation of Petroleum and of Natural Gas," *Third World Power Conference*, sec. IV, Paper No. 12, Washington, 1936, p. 10.

[21] Valentine R. Garfias, "Proven Reserves in Mineral Fuels in United States," *Transactions of the American Institute of Mining and Metallurgical Engineers, Petroleum Development and Technology, 1935*, p. 244.

[22] Statement of Alex W. McCoy, *Petroleum Investigation, Hearings on H. Res. 441*, 1934, pp. 1071–1081.

[23] Statement of E. W. Marland, *Petroleum Investigation, Hearings on H. Res. 441*, 1934, pp. 1439–1445. Estimates are probably as of the middle of the year.

[24] Statement of Campbell Osborn, *Petroleum Investigation, Hearings on H. Res. 441*, 1934, pp. 1458–1463.

[25] Warren L. Baker, "United States Crude Reserves Enlarged During 1935," *Oil Weekly*, Feb. 10, 1936, pp. 19–22.

[26] Joseph E. Pogue, "The Economic Structure of the American Petroleum Industry." *Third World Power Conference*, sec. II, Paper No. 5, Washington, 1936, p. 13.

[27] V. Garfias and R. V. Whetsel, "Proved Oil Reserves," *The Science of Petroleum*, I, 533.

[28] "Crude Reserves Shown by Fields," *Oil and Gas Journal*, Jan. 28, 1937, p. 37. These estimates are based on American Petroleum Institute, Jan. 1, 1935, estimate increased by new discoveries during 1935 and/or 1936 and decreased by production of those years.

[29] E. B. Swanson, "Petroleum and Natural Gas," Mimeo. Release #14860, Petroleum Conservation Division, U. S. Department of the Interior, November 1937.

[30] Walter A. Ver Wiebe, "Future Reserves of Oil," *Science of Petroleum*, I, 68–69.

[31] L. G. E. Bignell, *Oil and Gas Journal*, Jan. 27, 1938, pp. 38–39.

[32] W. V. Howard, "Known Reserves Must Increase Rapidly to Keep Pace With Future Demands," *Oil and Gas Journal*, Feb. 10, 1938, pp. 13–14.

[33] L. G. E. Bignell, "Reserves of More Than 500,000,000 Barrels Added During 1937," *Oil and Gas Journal*, Jan. 27, 1938, pp. 38–39.

[34] Alex W. McCoy, *Estimate of Petroleum Reserves, United States*, Ponca City, Oklahoma, January 1938.

[35] Wm. J. Kemnitzer, *Rebirth of Monopoly*, New York, 1938, p. 67. Same as Jan. 1, 1929, estimate with cumulative production deducted.

[36] Alex W. McCoy, *Estimate of Petroleum Reserves, United States*, Ponca City, Oklahoma, September 1938. Estimated as of Sept. 1, 1938.

[37] L. G. E. Bignel, "Reserves of Crude Oil Establish New High," *Oil and Gas Journal*, January 12, 1939, p. 20.

[38] "A. P. I. Estimates Reserves at 17 Billion Barrels," *Oil and Gas Journal*, March 2, 1939, p. 21.

[39] "World Oil Reserves Put at 31 Billion Barrels," *Oil and Gas Journal*, February 16, 1939, p. 32.

In every year since 1920 at least one estimate has been made of the petroleum reserves. Although these estimations have been made by a number of individuals and organizations, sometimes simply by computing back to prior years, they are, on the whole, consistent with each other. They serve to indicate that the rise in the known reserves of oil is greater than the rise in production.[13] On January 1, 1938, cumulated oil production in the United States amounted to about 20 billion barrels, and the estimate of the American Petroleum Institute indicated that ultimate recovery would approximate 36 billion barrels. Variations among authorities as to the size of the reserves are still considerable. It may be noted in table 1 that for January 1, 1938, these estimations vary from about 13 billion to about 19 billion barrels. The figure for January 1939 of 17.3 billion barrels by a committee of the American Petroleum Institute is most often used by members of the industry; the Institute's annual estimates are built up from district estimates in which local geologists and engineers participate. During 1938 proven reserves, according to one estimate, increased by nearly 1 billion barrels after allowance for estimated production of 1.2 billion barrels. The reserve estimate of the *Oil and Gas Journal* for January 1939 was 14.4 billions, or 0.9 billions above the original estimate of January 1938. During the year reserve revisions and extensions amounted to 1.12 billions and new discoveries to 0.95 billions according to the *Oil and Gas Journal* and to 2.24 billions and 0.81 billions, respectively, according to the American Petroleum Institute Committee.[14]

Variations among estimations at a given time are not surprising, since differences in judgment can easily be made concerning the size of local fields, the conditions in the reservoir, and, most important, the recovery factor.[15] In addition, some of the variations in estimates may result from different degrees of familiarity with particular fields. The difference between the 1938 estimates of the American Petroleum Institute and those of the *Oil and Gas Journal*, for example, relates almost entirely to the variations in estimates for Texas and Oklahoma. Moreover, there may be differences in judgment as to what areas can be considered to be proven or as to how many producing zones or depths are to be included in the estimate.[16]

Estimates of the reserves of natural gas were not made until recent years. As indicated above, there are difficulties in arriving at such totals. In 1930 Huntley and Mason estimated the reserves of the gas to be produced with oil in the United States east of the Rockies at a minimum of 49.5 trillion cubic feet (table 2). In 1930, H. O. Caster, of the Henry L. Doherty Co., estimated a reserve of 30 trillion cubic feet.

TABLE 2.—*Estimates of natural gas reserves in the United States, 1930–38*

	Trillions of cubic feet	Date of estimate
L. G. Huntley and S. L. Mason	[1] 68	May 1930.
H. O. Caster	[2] 30	October 1931.
H. A. Ley	[3] 75	November 1934.
V. R. Garfias	[4] 40	January 1935.
Ralph E. Davis	[6] 62	May 1935.
N. G. McGowen	[5] 62	May 1938.
Ralph E. Davis	[6] 66	April 1938.
Ralph W. Richards	[7] 100	October 1938.

[1] L. G. Huntley and S. L. Mason, "Gas and Coal Reserves in Relation to Pipe Lines and Markets," *National Petroleum News*, May 14, 1930, pp. 34–36. Their estimate was 49.5 trillion cubic feet and applied only to gas produced with oil at a ratio of 2,250 cubic feet of gas to the barrel of oil in the United States east of the Rockies. If this ratio is applied to their estimate of oil reserves of 8 billion barrels in California, a total estimate of casinghead-gas reserves for the United States of about 68 trillion cubic feet is obtained.

[2] H. O. Caster, "Conservation of Natural Gas Essential," *Oil and Gas Journal*, Oct. 22, 1931, p. 17. Estimate for 13 principal fields.

[3] Dr. John W. Finch, Director, U. S. Bureau of Mines, "Natural Gas Reserves and Their Conservation," *American Gas Association Monthly*, December 1936, p. 433. Estimate includes gas which will be lost.

[4] V. R. Garfias, "Proven Reserves of Mineral Fuels in the United States," *A. I. M. M. E., Pet. Dev. Tech., 1935*, p. 244; also U. S. Bureau of Mines, *Third World Power Conference*, Washington, 1936, sec. IV, Paper No. 12, p. 12.

[5] Neil Williams, "Conservation and Utilization of Gas Chief Topics at New Orleans Annual Meeting," *Oil and Gas Journal*, May 19, 1938, p. 38.

[6] Ralph E. Davis, "The Natural Gas Supply of the United States," presented before the Mid-West Gas Association, St. Paul, Minn., Apr. 12, 1938; also in *Gas*, May 1938, p. 29.

[7] Ralph W. Richards, "Natural Gas Reserves of the United States," pt. two, sec. I, p. 296 of this report.

The natural gas reserves of the United States have been estimated, as of the first part of 1938, at 62 trillion cubic feet by N. G. McGowen, president of the Natural Gas Association, and at 66 trillion cubic feet by Ralph E. Davis, natural gas engineer (table 2). In a later section of this report, Ralph W. Richards, of the United States Geological Survey, points out that recent discoveries in California raise the total to the order of magnitude of 100 trillion cubic feet.[17] On the whole, these estimates indicate that natural gas, as well as crude oil, is being discovered more rapidly than it is being consumed.[18] The variation in estimates probably results in part from differences in the percentage of recovery used, i. e., in allowances for underground and surface losses.

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[13] *Ibid.*, fig. 6.

[14] L. G. E. Bignell, "Reserves of Crude Oil Established New High," *Oil and Gas Journal*, January 12, 1939, pp. 20–23; "A. P. I. Estimates Reserves at 17 Billion Barrels," *Oil and Gas Journal*, March 2, 1939, p. 21.

[15] A slight variation in the percentage of oil in place that may be recovered leads to a considerable variation in the total reserve; see footnote 3 of this chapter.

[16] It is important to bear in mind that these estimates are restricted to natural reserves of crude oil, not including the potential supply of coal or shale, and that they relate to current operating practice and make no allowance for possible future improvements in recovery or changes in production methods. For example, the reserves which can be recovered by mining for oil are not included. It is estimated that oil shales could yield approximately 92 billion barrels of crude oil, and one estimate is available which indicates a possible yield from coal of nearly 600 billion barrels. See Federal Oil Conservation Board, *Report II to the President of the United States*, 1928, p. 4, and Ralph Arnold and W. J. Kemnitzer, *Petroleum in the United States and Possessions*, New York, 1931, p. 51.

[17] See pt. two, sec. I, ch. 3, of this report.

Reserve Estimates for the Individual States or Regions

As already indicated, the major differences in the estimates of crude-oil reserves relate to the States of Oklahoma and Texas. For individual States, three sets of available estimates are presented in table 3, which indicates that for Texas the maximum estimate is 41 percent greater than the minimum, and that for Oklahoma the maximum is 55 percent greater than the minimum. The estimates of Alex W. McCoy are the largest for Oklahoma and Kansas, whereas for Texas the largest estimate is that of the American Petroleum Institute.

TABLE 3.—*Comparative estimates of crude petroleum in the United States, by districts, January 1, 1938*

[Millions of 42-gallon barrels]

	American Petroleum Institute [1]	*Oil and Gas Journal* [2]	Alex W. McCoy [3]	Maximum estimates	Percent maximum over minimum [4]
California	3,063	2,990	2,700	3,063	13
Rocky Mountain States:					
Wyoming	266	312	215	312	14
Montana	109	52	47	109	133
Colorado	19	20	14	20	41
Total	394	384	276	441	...
Central and Southern States:					
New Mexico	547	623	430	623	45
Texas	8,218	6,868	5,870	8,218	41
Oklahoma	1,212	952	1,480	1,480	55
Kansas	601	636	747	747	24
Arkansas	192	80	138	192	140
Louisiana	713	595	698	713	20
Total	11,513	9,754	9,363	12,203	...
Eastern States:					
Illinois	41	39	50	50	29
Indiana	3	3	11	11	320
Kentucky	38	31	30	38	28
Michigan	49	43	78	78	83
New York	61	26	40	61	136
Ohio	28	18	36	36	95
Pennsylvania	288	188	300	300	60
West Virginia	28	13	25	28	110
Total	536	361	570	602	...
Total, United States	15,506	13,489	12,909	16,309	...

[1] *American Petroleum Institute Quarterly*, April 1938, p. 12; also in *Oil and Gas Journal*, Feb. 21, 1938, p. 41.

[2] *Oil and Gas Journal*, Jan. 27, 1938, p. 39.

[3] Alex W. McCoy, *Estimate of Petroleum Reserves, United States*, Ponca City, Okla., Jan. 6, 1938.

[4] Calculated from figures expressed in thousands of 42-gallon barrels.

If, for each of the States, the maximum of the estimates in table 3 is used, an estimate of 16.3 billion barrels of crude oil is obtained for the country as of January 1, 1938. It can be argued that this estimate is as acceptable as the other three. In any event, it is clear from all estimates that roughly half the total proven crude oil reserves of the country are located in Texas. Particularly within the past 5 years Texas reserves have been discovered much more rapidly than oil has been produced. Other considerable increases in reserves between January 1934 and January 1939 were recorded for Louisiana, Kansas, New Mexico, California, and Illinois.

Among gas-producing regions, by far the largest reserves are located in the midcontinent and Gulf coast sections. Davis estimates that these two districts account for 51 trillion cubic feet of natural gas reserves, or nearly 80 percent of the national total (table 4).[19] The estimate of McGowen is 4 trillion cubic feet less. For California, Davis presented an estimate of 6.9 trillion cubic feet, whereas a previous estimate of 11 trillion cubic feet or more had been made,[20] and a much larger estimate has recently been published.[21]

TABLE 4.—*Estimates of natural-gas reserves in the United States, by districts, 1938*

	Ralph E. Davis [1]	W. G. McGowen [2]
	(trillions of cubic feet)	*(trillions of cubic feet)*
Appalachian district	6.0	
North Central States	.1	
Midcontinent and Gulf coast	51.0	[3] 47.0
Rocky Mountain region	1.5	
California	6.9	...
Unaccounted for	.5	...
Total	66.0	62.0

[1] Ralph E. Davis, "The Natural Gas Supply of the United States," presented before Mid-West Gas Association, St. Paul, Minn., Apr. 12, 1938; also in *Gas*, May 1938, p. 29.

[2] Neil Williams, "Conservation and Utilization of Gas Chief Topics at New Orleans Annual Meeting," *Oil and Gas Journal*, May 19, 1938, p. 34.

[3] Includes all of New Mexico.

The two largest gas fields in the country are the Panhandle field in Texas and the Hugoton field in western Kansas and Oklahoma. These two fields comprise nearly half the known reserves in the entire United States.[22] The Amarillo field was estimated in 1936 to contain over 16 trillion cubic feet.[23] The Hugoton field was estimated in 1938 to contain over 14 trillion cubic feet.[24] One of the greatest problems in the natural gas industry relates to the location of the great reserves in the southwestern Great Plains district, far from centers of consumption. For example, to bring natural gas from the Southwest to the industrial Northeast involves heavy expenditures for rights of way and construction, as well as high operating costs in maintaining pressures.[25] The cost of transportation sets limits to the value of these natural gas reserves.

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[18] Although the estimate of H. A. Ley of 75 trillion cubic feet, in November 1934, is higher than most recent estimates, it should be noted that it included gas which would be lost and may have included some estimates for unproven areas.

[19] The gas reserves of the Appalachian district were recently estimated by E. E. Roth, of the Columbia Engineering Corporation, at 5 trillion cubic feet in comparison with the 6 trillion cubic feet given in the above table. *Oil and Gas Journal*, April 21, 1938, p. 25.

[20] Finch, *loc. cit.*

[21] See statement by Ralph W. Richards, pt. two, sec. 1, ch. 3, of this report.

[22] Ralph E. Davis, "The Natural Gas Supply of the United States," *Gas*, May 1938, p. 29.

[23] Finch, *loc. cit.*

Variations in Quality of Reserves

Estimates of the quantities of oil and gas in reserves do not disclose their value, because properties of oil and gas vary widely. Perhaps the most important indicator of the quality of crude oil is its specific gravity, which is usually directly related to the percentage of gasoline that can be obtained by straight-run methods. It also bears some relationship to the additional fractions of gasoline which can be secured by the cracking of the balance of the crude.[26] Consequently the price of crude within a district will depend primarily on the gravity of the crude.[27] Among districts, price differentials of course reflect differences in place utility as well as in gravity.

Unfortunately, no attempts have been made to classify reserves according to gravity. Some indication, however, may be obtained from a consideration of the crude produced from present producing fields. At least the horizontal extension of present fields is likely to yield a crude of about the same chemical characteristics as that being produced in the older part of the field. It would be logical, then, to expect that the extension of reserves in the Rocky Mountain district, in the Texas inland areas, and in the Oklahoma-Kansas fields would result in obtaining reserves of relatively light gravity. There is the same likelihood that the extension of pools in the Gulf coast district and in much of California would add to reserves in crude oils of relatively heavy gravity. On the other hand, the gravity of the oil now being produced from a field furnishes little indication of the gravity of the oil in the reserves lying in deeper strata in the same area. Indeed, in the Gulf coast fields of Louisiana and Texas the deeper producing horizons very often yield a crude of unusually light gravity, some yielding a distillate almost suitable for a motor fuel without refining.[28]

Variations in the percentage of sulphur also affect somewhat the quality of the crude, but improvements in refining methods have made it possible to obtain a satisfactory gasoline from sulphurous oils, hence they usually sell at only a small discount. The percentage of sulphur in reserves in different sections of the country may be determined to a high degree of accuracy from analysis of core samples as well as from an examination of crude already produced.[29]

In the case of natural gas also the amount of sulphur is an important consideration in judging the quality of the reserves. For example, that part of the Panhandle gas field which produces "sour" gas obtains less for its product than does the "sweet" gas section of the field. So far as is known, the reserves in the great Hugoton field—southwestern Kansas and the Panhandle of Oklahoma—contain sweet gas.

Average Depth of Reserves

The average depth of each field which is included in the estimate of proven reserves is, of course, known, but no attempt has been made to present reserve data according to average depth, either by fields or by States. The average depth of a field gives some indication of the cost of obtaining the raw materials. Although most of the shallower oil and gas fields in the country have probably been discovered and exploited, it is not unlikely that many new fields will be discovered at depths of less than 3,000 feet; yet most of the major discoveries of the last decade have been in areas where the oil and gas strata lie from 3,000 to 7,000 feet below the surface. Some indication of the average depth of future producing fields can be obtained from data relating to the shallowest strata in new fields. In 1898, for example, the fields discovered were only a few hundred feet below the surface. The average depth has increased until fields discovered in the early 1930's had averaged approximately 4,000 feet below the surface (fig. 6).[30] Accompanying this development has been an increase in the maximum depths drilled. Whereas in 1890 the deepest well extended to approximately 5,500 feet, in 1938 an oil well had been drilled to slightly more than 15,000 feet.[30a] Moreover, the large number of wells drilled below 8,000 feet in the Louisiana and Texas coastal fields has led to the discovery of new reserves, while in California a much higher percentage of the very deep wells has been dry. A few of these deep wells in the coastal region as well as in California have been gas producers. The deepest producing well in 1938 was the Fohs Oil Co.'s Buckley No. 1, in Louisiana, which for a time produced oil at a depth of approximately 13,300 feet.

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[24] *Oil and Gas Journal,* July 14, 1938, p. 27.

[25] H. Stanley Norman, "Richest Market for Natural Gas Awaits Pipe Line Builders," *Oil and Gas Journal,* September 22, 1938, pp. 59, 80. In addition there is the cost of converting manufactured-gas distribution and consumer facilities to those suitable for natural gas.

[26] For average yields of gasoline, both straight-run and cracked, by districts, see U. S. Bureau of Mines, *Minerals Yearbook, 1938,* p. 869.

[27] Thus, in the Texas Gulf coast area in March 1939 crude oil brought from $0.78 per barrel for gravities of 18° and 19° A. P. I. (heavy) to $1.28 per barrel for gravities of 40° A. P. I. and over (light). *Oil and Gas Journal,* March 31, 1939, p. 234.

[28] The same applies to the Medicine Bow field, one of the newer fields in Wyoming, *Oil and Gas Journal,* April 28, 1938, p. 75. Yet other deep wells have yielded medium gravity crudes, *Oil Weekly,* July 25, 1938, pp. 70, 122.

[29] See Wilbur F. Cloud, *Petroleum Production,* University of Oklahome Press, 1937, table X, p. 144, for sulphur content of crude from major oil fields.

[30] O. E. Kiessling, H. O. Rogers, G. R. Hopkins, and others, *Technology, Employment, and Output-Per-Man in Petroleum and Natural-Gas Production,* National Research project, W. P. A Report E–10, 1939 (in press).

Differences in the depth of the crude oil reserves and in the rock formations through which wells must be drilled have a direct bearing on the cost of production. The latest available data on the distribution of petroleum reserves in the United States, according to estimated costs, are those issued by the Petroleum Administration Board as of 1934 (table 5). These estimates indicate that about 85 percent of the reserves could be produced at a cost of less than $1 per barrel. The next 10 percent of the reserves could be recovered only at costs rising to $1.60 per barrel.

TABLE 5.—*Petroleum reserves classified within cost limits, United States, 1934*

Production cost per barrel	Producible within cost limits	Cumulative
	Percent	*Percent*
$0–$0.39	16.30	16.30
$0.40–$0.79	45.92	62.22
$0.80–$0.99	22.47	84.69
$1.00–$1.19	5.39	90.08
$1.20–$1.59	4.50	94.58
$1.60–$1.99	2.57	97.15
$2.00 and above	2.85	100.00
Total	100.00	------

Source: Compiled from reports submitted to the Petroleum Administration Board in connection with its study of cost of producing crude petroleum.

Ownership of Reserves

Practically all the acreage in proven areas has been leased, and most of it is controlled either directly or indirectly by major oil-producing companies.

At the end of 1925 the successor companies of the old Standard Oil Co. of New Jersey controlled 47.4 percent of the acreage in proven oil-producing territory. Although all these holdings were not in rich producing areas, consolidations since 1925 and the acquisition of further reserves by the Standard Oil groups have substantially raised this percentage and raised the average quality of the holdings.[31] Recent detailed data indicate that a large percentage of reserves is now controlled by the following companies: Standard Oil Co. (New Jersey) and its subsidiaries, the Humble Oil and Refining Co. and the Creole Petroleum Corporation; Gulf Oil Corporation; Standard Oil of California; Texas Corporation; and Socony-Vacuum Oil Co.[32]

Foreign reserves controlled by American companies may be considered possible additions to reserves in the United States, although the ability of these companies to export crude to America might be called into question by the respective national governments once a "petroleum famine" is threatened. In any event, these American concerns have many foreign markets, especially in Europe, dependent on crude supplies from South America and other oversea sources. In Colombia the Texas Corporation and the Socony-Vacuum Oil Co. hold the largest concession of potential reserves, a block of 1,200,000 acres in the territory adjacent to Venezuela. In Venezuela, which ranks third in national output, the Standard Oil Co. (New Jersey) controls, roughly, 6,000,000 acres of proven and likely reserves. The holdings of the Gulf Oil Corporation may approximate 4,000,000 acres and those of the Royal Dutch Shell Co. 2,000,000 acres.[33]

Only a small percentage of the present oil and gas reserves is owned by the Federal Government, the oil reserve being estimated from 0.5 billion to 1.0 billion barrels.[34] In 1935 the production of petroleum on United States public lands amounted to only 28 million barrels.[35] Total oil reserves owned by the several states probably exceed Federal reserves.

[30a] Ralph Arnold and William J. Kemnitzer, *Petroleum in the United States and Possessions*, 1931, p. 90; "The Deepest Hole in the World," *Fortune*, July 1938, p. 50; T. P. Sanders, "Deep Well is Providing Grounds for Newest Methods," *Oil and Gas Journal*, April 28, 1938, p. 46.

[31] Federal Trade Commission, *Petroleum Industry: Prices, Profits, and Competition*, 1928, p. 78.

[32] From estimates presented in the *Monthly Market Letter* of Goodbody and Co., March 16, 1939. The estimated reserves of American oil companies in the United States and abroad, in millions of barrels, are as follows: Amerada, 210; Atlantic Refining, 210; Barnsdall, 215; Consolidated, 500; Continental, 310; Creole, 500; Gulf, 1,280; Humble, 1,400; Lion, 80; Ohio, 525; Phillips, 300; Pure, 450; Seaboard, 170; Shell Union, 500; Skelly, 155; Socony-Vacuum, 1,090; S. O. of California, 1,100; S. O. of Indiana, 520; S. O. of New Jersey, 3,800; Sun, 263; Texas, 1,100; Tide Water Associated, 329; and Union Oil of California, 275.

[33] "Gulf Oil," *Fortune*, October 1937, pp. 87, 148. According to Harry W. Laidler, it was estimated in 1930 that, of the output of crude oil, American companies controlled the following percentages: Colombia, 100; Peru, 81; Mexico, 71; Canada, 59; Venezuela, 40; Trinidad, 13; Poland, 7; Rumania, 7; Dutch East Indies, 2, *Concentration of Control in American Industry*, New York, 1931, p. 24.

[34] *Petroleum Investigation, 1934*, pp. 747, 2830. William J. Kemnitzer estimates that United States petroleum reserves of 0.7 billion barrels would be doubled if deeper sands were developed. The reserve would further be increased by 1 billion barrels, raising the ultimate supply to 2.4 billions, if the Navy were successful in obtaining title to the submerged lands off the coast of California. *Rebirth of Monopoly*, New York, 1938, p. 72.

[35] U. S. Geological Survey data, published in *Petroleum Facts and Figures, 1937*, p. 88.

Discovery of Reserves

Rate of Finding and Relation to Production

Estimates of annual discoveries of oil reserves, made in 1936 by H. J. Wasson, indicate the erratic course of discovery (table 6). Findings rose rapidly during the later 1920's to a peak in 1930 of 4 billion barrels, and then fell sharply before recovering to a peak of 2.25 billion barrels in 1937. Although the rate of discovery bears a certain relationship to industrial activity, chance factors have a considerable influence on the amounts which are added to known reserves each year. It is clear, however, that in every year since 1920 some reserves have been added and that the cumulative curve of ultimate production has risen (fig. 9).[36]

TABLE 6.—*Estimated petroleum reserves in the United States, 1919–37*

[Millions of 42-gallon barrels]

Year	Estimated reserve discoveries	Domestic production	Estimated net reserve change	Estimated total proved reserve at end of year	Estimated years' supply: In terms of future production[1]	Estimated years' supply: In terms of current production[2]
1919	-------	-------	-------	7,534	10.4	---------
1920	585	443	+142	7,676	9.9	17.3
1921	800	472	+328	8,004	9.9	17.0
1922	800	557	+243	8,247	9.9	14.8
1923	800	732	+68	8,315	9.8	11.4
1924	800	714	+86	8,401	9.9	11.8
1925	810	764	+46	8,447	9.5	11.1
1926	1,547	771	+776	9,223	10.0	12.0
1927	1,353	901	+452	9,675	10.0	10.7
1928	1,936	901	+1,035	10,710	10.5	11.9
1929	1,100	1,007	+93	10,803	10.3	10.7
1930	4,000	898	+3,102	13,905	12.1	15.5
1931	517	851	−334	13,571	11.3	16.0
1932	1,030	785	+245	13,816	11.1	17.6
1933	500	906	+406	13,410	10.4	14.8
1934	700	908	−208	13,202	9.9	14.5
1935	1,400	997	+403	13,605	9.8	13.6
1936	900	1,100	−200	13,405	9.3	12.1
1937	2,252	1,278	+974	14,379	9.7	11.3
1938[3]	2,076	1,201	+875	15,254	10.2	12.7

[1] In order to obtain the estimated life of the reserve as of the end of any indicated year, the subsequent production is accumulated until equal to the estimated reserve. After 1937 a projection of production figures was made by adding for each year 3 percent of the 1937 production, or 38,340,000 barrels. On the basis of average annual discoveries of 900 million barrels and production figures which increase 32 million barrels per year from an estimated 1936 level of 1,073 million barrels, Wasson in 1936 calculated that at the end of 1942 there would be an 8.1 estimated years' supply.

[2] Ratio of reserve at end of year to production during the year.

[3] Production figures preliminary. *Oil and Gas Journal*, January 12, 1939, p. 20 and January 26, 1939, p. 77.

Source: Based primarily on H. J. Wasson, "American Oil-Reserve Replenishment," *Transactions of the American Institute of Mining and Metallurgical Engineers, Petroleum Development and Technology, 1937*, p. 230; also in *Oil and Gas Journal*, Jan. 27, 1938, p. 38, and U. S. Bureau of Mines, *Minerals Yearbook, 1938*, p. 815.

Wasson estimates that in each year of the 1920's reserve discoveries exceeded domestic production, with the greatest net additions to proved reserves being made in 1926 and 1928. In 1930 discoveries were more than four times production, but during the next 6 years discoveries averaged less than withdrawals from the reserves. On the other hand, in 1937, with the great increase in discoveries, approximately 1 billion barrels net were added to proven reserves (table 6).[37] The net addition in 1938 was nearly as great.

The estimates of rates in oil finding by Wallace E. Pratt also indicate a peak in the period 1926–30 (table 7). Of the 196 major oil fields discovered in the United States from the end of 1900 to the end of 1935, 59 fields, or 30 percent, were found during that 5-year period. In the next 5 years, 1931–35, discoveries decreased and only 41 new fields were brought into production, or about the same as the number brought in during the early twenties, when there was such a fear of exhaustion of reserves. Within recent years an increasing percentage of new major fields has been found by geophysical methods and smaller proportions by geological methods and by obvious evidence (table 7).

TABLE 7.—*Major oil fields discovered in successive 5-year periods, classified as to methods of discovery, United States, 1901–35*

Period	Number [1]	Percent [1]	Number [2]	Percent [2]	Number [3]	Percent [3]	Number [4]	Percent [4]	Number [5]	Percent [5]	Number [6]	Percent [6]
1901–05	2	20	7	70	1	10	-----	0	-----	0	10	100
1906–10	2	40	2	40	1	20	-----	0	-----	0	5	100
1911–15	3	16.7	8	44.5	7	38.9	-----	0	-----	0	18	100
1916–20	1	4.3	4	17.4	17	73.9	-----	0	1	4.3	23	100
1921–25	13	32.5	10	25	17	42.5	-----	0	-----	0	40	100
1926–30	5	8.5	5.5	9.3	37	62.7	5.5	9.3	6	10.2	59	100
1931–35	5	12.2	-----	0	12.5	30.5	22.5	55.0	1	2.4	41	100
Total	31	15.8	36.5	18.6	92.5	47.3	28.0	14.3	8	4.1	196	100

[1] Discoveries resulting from purely random drilling.

[2] Discoveries resulting from obvious evidences.

[3] Discoveries resulting from geological observation.

[4] Discoveries resulting from geophysical investigation.

[5] Discoveries resulting from drilling deeper in territory already producing in shallow sands.

[6] Total discoveries since 1900 by 5-year periods.

Source: Wallace E. Pratt, "Discovery Rates in Oil Finding," *Oil and Gas Journal*, Mar. 25, 1937, p. 46.

The comparative drop in findings is more sharply indicated by a classification of annual discoveries in terms of quantities. Of the total discoveries during the period 1901–35, roughly 40 percent (or an annual average of about 2.2 billion barrels) occurred from 1926 to 1930, inclusive. In the following 5 years the annual average dropped to 0.7 billion barrels, or only 13 percent of the total. These increases in reserves were less than those made in the period 1921–25, when approximately 16 percent of the total was found.[38] Garfias and Whetsel contrast the annual average findings of the years 1931–34 of 0.58 billion barrels with the average production of 0.87 billion barrels and conclude "that very important new discoveries are necessary in the near future to compensate for aggregate depletions."[39]

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[36] Kiessling, *et al., op. cit.*

[37] It should be noted that in table 6 the estimate of reserves at the end of 1937 was 14.4 billion barrels in contrast with an estimate of 15.5 billion barrels by the American Petroleum Institute. Consequently, it is possible that Wasson's annual estimates of discoveries may have erred on the conservative side by a cumulative total of about 1 billion barrels since 1920.

For natural gas the list of estimates of proven reserves does not extend back far enough to indicate satisfactorily the growth of reserves or to make possible any clear comparison of the relation between increases in reserves and rate of consumption. The estimates do suggest, however, that new discoveries have exceeded consumption, at least during the 1930's (table 2). In relation to past production, present reserves loom larger for natural gas than for petroleum. The relation between cumulative production and reserves indicates that more petroleum has been produced than is at present "in sight;" whereas, natural gas reserves are probably half again as large as total production to date.[40]

Sizable supplies of natural gas are discovered accidentally. To some extent the growth of proven reserves of natural gas will depend on the search for oil. Moreover, since approximately half of the natural gas is produced in association with crude oil, it is safe to say that the rate of discovery of new gas reserves will vary somewhat in relationship to the actual discovery of crude oil. Yet it is possible that the development of the newer methods of oil production, under which natural gas is conserved underground or even reintroduced into the wells to maintain natural pressure for lifting purposes, may retard somewhat the availability of natural gas for commercial use.

Location of New Reserves

A large percentage of the reserves discovered between 1933 and 1938 were found in Texas, Louisiana, and Kansas (table 3).[41] Moreover, from January 1938 to January 1939 the most important discoveries of new reserves were in the coastal districts of Texas and Louisiana, and to a lesser extent in California and Illinois.[42] Texas continues to account for more than half the proven reserves.

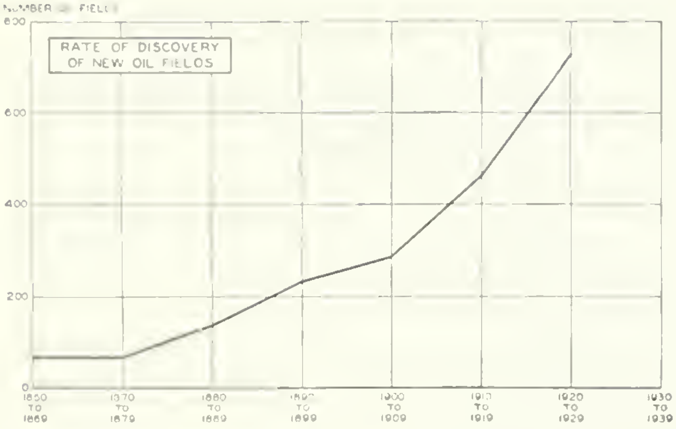

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FIGURE 2.–Discovery of New Oil Fields, by Decades, 1860–1930.

Likelihood of Extending Proven Reserves

In the past, proven petroleum and natural-gas reserves have increased fast enough to keep up with production. Since much of the total output comes from flush pools, operators have extended exploration more or less in relation to the rise in consuming activity.

The likelihood of extending old producing fields is probably greater than that of discovering new sources of oil or gas. In fact, in the last few years additional reserves have been recorded more through an upward revision of estimates of previously discovered fields.[43] After a period of production, many fields have been extended either by drilling to deeper strata or by drilling in adjacent territory. One of the most dramatic vertical extensions of an old field was the tapping of deeper producing horizons in the Santa Fe Springs field in California in 1929. Production increased from 16 million barrels in 1928 to 77 million barrels in 1929.[44] Spindletop, a comparatively old field, was revived in 1927 by deep drilling. Perhaps a majority of the new fields discovered in the last decade have been extended over a wider area, sometimes by deeper or shallower drilling in contiguous sections. For example, the Oklahoma City field was enlarged by the Capitol extension in 1936, and the Panhandle field in Texas was considerably extended in 1929.

The discovery of new oil and gas fields depends upon a number of factors, but more important probably are changes in prices of oil or gas, changes in business conditions, the development of exploration methods or drilling techniques, and mere chance discovery. Some

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[38] Wallace E. Pratt, "Discovery Rates in Oil Finding," *Oil and Gas Journal*, March 25, 1937, p. 46.

[39] Garfias and Whetsel, *loc. cit.*

[40] Up to the beginning of 1938 the cumulative production of petroleum approximated 20 billion barrels, whereas the reserves approximated 16 billion barrels. On the other hand, for natural gas, cumulative production approximated 40 trillion cubic feet, whereas reserves were 62 to 66 trillion cubic feet. See pt. two, sec. 1, ch. 2, fig. 6, of this report; and pt. two, sec. I, ch. 3, fig. 9 of this report.

[41] Pt. two, sec. I, ch. 2, table 5, of this report; and Alex W. McCoy, *Estimate of Petroleum Reserves, United States*, Ponca City, Oklahoma, January 1938, pp. 23–41.

[42] *Oil and Gas Journal*, January 12, 1939, pp. 20–23, and March 2, 1939, p. 21.

[43] See E. B. Swanson, *Petroleum and Natural Gas*, mimeographed release of the Petroleum Conservation Division, U. S. Department of the Interior, November 1937, p. 2. The *American Petroleum Institute Quarterly*, April 1938, p. 12, shows that, in 1937, 2.8 billion barrels were added to reserves by the revisions of estimates for old fields and only 0.9 billion barrels by discovery of new reserves.

[44] U. S. Bureau of Mines, *Mineral Resources of the United States, 1929*, pt. II, p. 443.

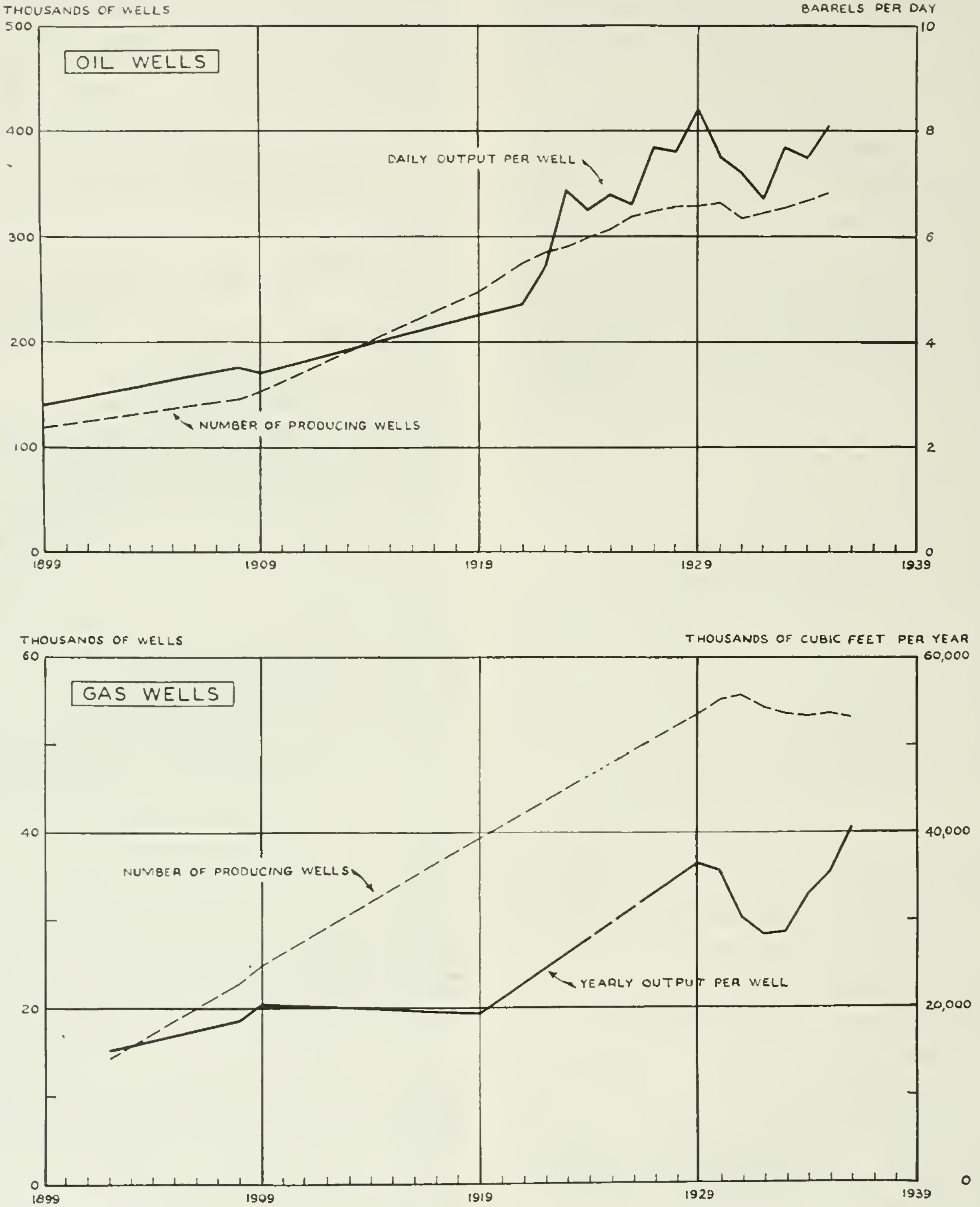

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FIGURE 2A.—Trend of Number and Average Output of Oil and Gas Wells, 1899–1936.

oil producers hold that the extent of discovery is primarily a function of price and regard decreased discoveries between 1931 and 1934 as substantiating proof.[45] The marked drop in discoveries during the early 1930's is indicated in table 6. (It is to be noted, however, that in 1932 with business conditions bad, especially in the oil industry, there were estimated new discoveries of over 1 billion barrels; this perhaps is an indication of the chance factor in the finding of new pools.) On the other hand, it has been pointed out that a rising price failed to bring out a commensurate increase in discoveries during the war period (1915–20).[46] Other producers hold that the failure of the discovery rate to maintain its pace in the early 1930's probably was explained more by the inadequacy of finding techniques to cope with the increasing difficulty of discovery than by the effect of the industrial depression.[47] If prices of oil and gas remain high for a period of several years, increased exploratory efforts very likely will be successful in adding considerable amounts to the size of reserves.

Continued improvement of exploration methods and drilling procedures undoubtedly will result in an increase in supplies of oil and gas. Recent developments in these spheres of activity are treated in part three, section II, of this report, but it should be said here that considerable confidence is being placed in geological methods of discovering "stratigraphic pools"; that is, pools of the East Texas type, where the reservoir is of the stratigraphic or shore-line type rather than of the dome type. Although a deliberate search for such "lens-type" pools may lead to an increase in the ratio of dry holes to producing wells, the discovery of important additional reserves may result.[48] Moreover, the development of deeper drilling and also directional drilling has indicated the possibility of reaching new producing zones and thus obtaining sizable oil reserves in many old producing regions. Directional drilling may make it possible to tap reserves located offshore. Considerable reserves are known to exist just off the California coast and off the Gulf coast of Texas and Louisiana. Slanted wells have actually accounted for nearly 30 million barrels of crude oil production since 1933 in the Huntington Beach section in California.[49]

Although the difficulty of discovering new fields has risen somewhat in the last decade, there remain large areas in which some oil and gas production is possible.[50] A likely area estimated at 650 million acres remains unexplored.[51] In this territory fragmentary information indicates the existence in many places of extensive formations in sedimentary rocks which are productive in neighboring districts and the existence of other geologic factors favorable to the occurrence of oil.[52] Moreover, this territory may lead to production in more than one producing zone. On the other hand, it should be noted that exploration has indicated no new petroliferous strata in the past few years and that only one new geological province has been proved to be oil bearing in the past 15 years, namely, the Permian Basin area in western Texas and eastern New Mexico. Although of considerable importance, this area in its peak year contributed "less than half the daily production required from at present undiscovered fields to prevent a shortage in 1940."[53] Moreover, only three States—Arkansas, New Mexico, and Montana—have been added to the list of producing States in the past 30 years, and the proved reserves in these States account for only about 3 percent of the national total.

Recent discoveries of new reserves, however, indicate no immediate falling off in the discovery rate. During 1938 revisions, extensions, and new pool reserves were set at 3,054 million barrels by the American Petroleum Institute.[54] Practically all the new proven underground supply was located in six States—Texas, 1,675 million barrels; Louisiana, 422 millions; California, 375 millions; Illinois, 226 millions; New Mexico, 192 millions; and Oklahoma, 125 millions. Of major producing States, only Oklahoma failed to add to known reserves more than was withdrawn by production.

Recent discoveries of natural-gas reserves have occurred mainly from the extension of oil fields and from the extension of the Hugoton natural-gas field. The reserve of this field in southwestern Kansas is now estimated at 14.25 trillion cubic feet.[55] Further additions to reserves in the Appalachian region are being made by the development of the Oriskany sands.[56]

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[45] J. M. Lovejoy, *A. I. M. M. E., Pet. Dev. Tech., 1937*, p. 258.

[46] Cf. L. C. Snider and B. T. Brooks, "Probable Petroleum Shortage," *Bulletin of American Association of Petroleum Geologists*, January 1936, p. 38. It is indicated here that increased prices cannot bring about increased production from areas which are "worked out."

[47] Pratt, *op. cit.*, pp. 46, 48.

[48] Pratt, *op. cit.*, pp. 48–50; Joseph E. Pogue, "The Economic Structure of the American Petroleum Industry," *Third World Power Conference*, Washington, D. C., 1936, sec. II, Paper No. 5, p. 15.

[49] Charles B. Leyendecker, "Gulf Coast Is World's Most Active Deep Drilling Center," *Oil Weekly*, July 25, 1938, p. 104; William J. Kemnitzer, "Billion Barrels May Ultimately Be Secured Off Pacific Coast," *Oil and Gas Journal*, November 18, 1937, pp. 39–40.

[50] See pt. two, sec. I, ch. 2, fig. 8, of this report.

[51] John D. Gill and E. T. Knight, "What are the Uneconomic Uses of Petroleum?" *A. I. M. M. E., Pet. Dev. Tech., 1938*, p. 291, n. 20. The American Petroleum Institute has set the figure at 1 billion acres.

[52] Pogue, *loc. cit.*

[53] Snider and Brooks, *op. cit.*, p. 17.

[54] *Oil and Gas Journal*, March 2, 1939, p. 21. During 1938 it was clear that sizable additions to reserves were being made and that the coastal Texas and Louisiana section was leading in discoveries. Many new small fields were discovered in western Kansas and southern Texas. See *Oil Weekly*, July 25, 1938, pp. 61–70, 120, and August 8, 1938, p. 20, and *Oil and Gas Journal*, July 28, 1938, p. 127. There are indications of considerable further extensions of reserves under submerged lands off the California coast; William J. Kemnitzer, *op. cit.*, pp. 39–40; Brad Mills, "California Is in Another Major Discovery Cycle," *Oil Weekly*, June 15, 1938, p. 32. For Illinois, important further additions to proven reserves are anticipated; Dorsey Hager, "Geologist Has Optimistic View of Oil Possibilities in Illinois," *Oil and Gas Journal*, August 11, 1938, p. 25.

The likelihood of increasing proven oil and gas reserves depends considerably on possible increases in the relative recovery of these reserves. Increases in recovery may be expected to result if there is a rise in the price of oil and gas, if the law of capture relating to the production of these resources can be further modified, or if new recovery methods, including mining for oil, are perfected. Relative recovery has risen greatly in recent years, owing both to improved procedure and to better operating methods. Yet the high percentage of oil which is still being left in the ground, perhaps as much as 65 percent on the average, presents great rewards for any slight improvement in drilling or production technique. Indeed, it has been suggested that the possibility of expanding oil and gas supplies by raising the relative recovery is much greater than that of finding new producing areas.[57] A rise in the price of crude may allow present recovery methods to be applied more generally as well as give impetus to further technical improvement. Thus rising prices would augment the present recoverable supply of petroleum.[58] Considerable importance may attach to the mining of oil and the development of other methods of secondary recovery if the price of crude should rise high enough.[59]

Moreover, the possibility of changes in the legal regulations which relate to the production of oil and gas, in particular the law of capture, may facilitate much more efficient field operation and hence increase the relative recovery of resources. In fact, much of the waste in the production of natural gas and oil is attributable to the competitive development of fields, whereby excessively large numbers of wells are rushed to completion in order to capture some of the valuable reserves which lie in a pool extending under the land of several property owners. Garfias has maintained that no permanent remedy for waste in recovery can be expected "until the law of capture is superseded or basically modified to make possible the economic development and exploitation of oil and gas fields through the unit plan of operation or some other similar effective method."[60] Already, proration and well spacing have materially reduced waste.

On the average, future discoveries of oil undoubtedly will be made with greater difficulty, although it is possible, even probable, that in some years very large reservoirs of oil or gas, with subsequent flush production, will be discovered. Very likely there will be no greater regularity in the future than in the past. The discovery of new pools proceeds on the basis of elimination. Each new pool means one less to be discovered. Although the discoveries may remain high for some time, a period must arrive when the size of reserves discovered will begin to show decreases. Proven reserves are at their highest level at the present time (February 1939), but the size of such reserves gives no indication of the number of pools yet to be found. This problem depends more on the extent to which possible oil-bearing areas already have been explored by wildcat activity. Undoubtedly the future will witness greater expenditures for exploratory efforts, including stratigraphic methods as well as deeper drilling.

Rate of Exhaustion

Past Rates

Oil reserves of the United States have been estimated in terms of annual production, either as recorded for the past or as anticipated for the future. Thus, Wasson's estimate for the end of 1919 of 7.5 billion barrels was equivalent to production during the next 10.4 years (table 6). His estimates of the life of reserves in terms of future years' production held at about 10 years during the 1920's and rose sharply in 1930, but since then new discoveries have been inadequate to maintain the estimated years' supply at the 1930 level (12.1 years), despite the great increase in discoveries in 1937 and 1938.

Substantially the same trend in life of reserves is indicated by figures showing the ratio of estimated reserves at the end of the year to production during the same year (table 6). These figures show that reserves at the end of 1920 were 17.3 times production of that year. This reserve-production ratio fell to 10.7 at the end of 1929, recovered to 17.6 in 1932, dropped steadily to 11.3 in 1937, and rose to 12.7 in 1938. These data are sufficient to indicate that there has been a considerable decrease in the 1930's in the size of reserves in terms of the past year's output.

As indicated earlier in this chapter, the cumulative crude oil production amounts to somewhat more than

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[55] *Oil and Gas Journal*, July 14, 1938, p. 27.

[56] Davis, *loc. cit.*

[57] A. T. Shurick, "High-Cost Proved but Unworked Oil Reserves May Be Key to Future Supplies," *Annalist*, November 19, 1937, p. 854.

[58] V. H. Wilhelm, Chief Petroleum Engineer, The Texas Corporation, *A. I. M. M. E., Pet. Dev. Tech., 1937*, p. 257.

[59] See p. 358 of this report. Moreover, it has been reported that Soviet engineers have increased recovery of oil reserves by thermic methods whereby heated gas is forced into the wells under pressure, and "the oil is separated from the sand and pushes through to the wells, and is pumped out in a liquid state or comes out of itself as a gas, which is then refined into oil products." *Oil and Gas Journal*, March 4, 1937, p. 56.

[60] V. R. Garfias, "Proven Reserves of Mineral Fuels in the United States," *A. I. M. M. E., Pet. Dev. Tech., 1935*, p. 244.

50 percent of all reserves which have been discovered up to the beginning of 1938.[61] On the other hand, less than 40 percent of the discovered reserves of natural gas have already been produced.[62]

Estimated Life of Known Reserves

Pogue has estimated that the life of known reserves in terms of the past year's production has varied between 10 and 15 years since 1910.[63] The *Oil and Gas Journal* estimate of known reserves at the end of 1938 indicates that reserves were equivalent to 11.8 times the year's production (table 6).[64] For 1937 the ratio was 10.6; the comparable figure based on A. P. I. data was 12.1. This term of life, however, does not mean that known reserves could be produced within 12 years, because the recovery of crude has to be spread over a period of many years. It is more likely that present reserves would be adequate for 4 or 5 years at roughly the current level, for an additional 4 or 5 years' production at about one-half the 1938 level, and for many additional years' output at something like one-tenth of this production. Ordinarily faster initial production means a decrease in ultimate recovery.

For natural-gas reserves the estimated life, in terms of the 1937 production of 2.37 trillion cubic feet, is about 28 years if Davis' estimate of reserves of 66 trillions is used. Davis himself, however, estimates the life of the reserve at 30 years.[65] N. G. McGowen, president of the American Gas Association, estimated reserves at 62 trillion cubic feet and pointed out that, at the rate of withdrawals during 1936, the reserves would have a life of 28.5 years, whereas, at the rate of withdrawals of 1937, the life would be reduced to somewhat less than 25 years.[66] Estimates of the life of natural-gas reserves have been rising somewhat in recent years because of the extension of discoveries.[67] Richards' optimistic estimate indicates a reserve life of 42 years (table 2).

Importance of Flush Production

A large percentage of the crude oil produced at the present time is contributed by flush wells—that is, wells in fields of comparatively recent discovery in which natural gas in the geological structures supplies the lifting power. Snider and Brooks estimated, at the end of 1935, that approximately half of the current production was attributed to these new flush wells, which constituted only about 2 percent of the total number of wells in production.[68] When a new field is discovered, a large percentage of the total reserves is produced in a few years, unless an effective plan of proration of production or of restriction of well drilling is in effect. A measure of the rapid rise and decline of flush fields is illustrated by the history of the Seminole district in Oklahoma. In October 1926 the greater Seminole field, with only 37 wells completed, had a daily production of about 81,000 barrels. Within a year more than 600 additional wells were drilled, and in 1927 the field reached peak production at 136.0 million barrels for the year. Production declined 70 percent by 1931, amounting in that year to 40.5 million barrels. Afterward the decline was slower, and in 1937 output was 30.5 million barrels. Perhaps the general effect of declining output from flush fields is better illustrated by the fact that production from all fields operating in 1929 declined about 40 percent in 5 years, or a drop from 1.0 billion barrels to 0.6 billion barrels in 1931.[69] In other words, a serious shortage would have developed if the East Texas field or fields of similar magnitude had not been discovered.

Moreover, evidence indicates that until recent years the peak of flush production was becoming more pronounced. Thus, of a number of oil fields for which Snider presents a measure of drop in output from the peak year, an analysis shows that, before 1920, fields did not fall below 50 percent of their peak year's production until they had been in operation somewhat more than 4 years. For the years 1921–31 the new fields, on the average, fell below 50 percent of peak production somewhat more than 2 years after the peak had been reached.[70]

Since the early 1930's state regulations restricting drilling and production have had the effect of holding back flush production during the initial stages of operation of new fields. Likewise, the Petroleum Code Authority under the National Recovery Administration and the Interstate Oil Compact Commission, which followed it, facilitated production planning and the introduction of rational proration measures in many States. But in others, especially in Illinois, the old evils of flush production are still present in an aggravated form, largely because of the lack of adequate legislation.[70a]

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[61] See pt. two, sec. I, ch. 2, fig. 6, of this report. If the American Petroleum Institute estimate of 15.5 billion barrels as of January 1, 1938, is used, the percentage is 56 percent, or 20 billion compared to 35.5 billion. If the most liberal current estimate of reserves, that of W. J. Kemnitzer of 19.0 billion barrels, is used, the estimated percentage exhaustion figure is 51 percent. See table 1, above.

[62] Cumulative production at the end of 1937 is placed at 40 trillion cubic feet. If the remaining reserve was taken as 66 trillion cubic feet, then 62 percent of all discoveries were still available; if at 100 trillions, then 71 percent. See table 2, above.

[63] Pogue, *op. cit.*, p. 8.

[64] *Oil and Gas Journal*, January 12, 1939, p. 20.

[65] Davis, *op. cit.*

[66] Neil Williams, "Conservation and Utilization of Gas," *Oil and Gas Journal*, May 19, 1938, pp. 38–39.

[67] Garfias, *A. I. M. M. E., Pet. Dev. Tech., 1935*, p. 244; U. S. Bureau of Mines, "Conservation of Petroleum and Natural Gas," *Third World Power Conference* (Washington, 1936), sec. IV, Paper No. 12, p. 12.

[68] Snider and Brooks, *op. cit.*, p. 16.

[69] Snider and Brooks, *op. cit.*, p. 23.

[70] L. C. Snider, "A Comparison of Old and New Oil Fields," *A. I. M. M. E., Pet. Dev. Tech., 1933*, pp. 82–83.

Life of Pools and of State Reserves

Although the production life of pools varies from 4 to 30 years, and occasionally even longer, the flush production stage, when relatively large percentages of the contents of the reservoir are produced, is very short. In recent years more intensive drilling, facilitated by the ability to sink wells in a few weeks, has tended to offset the effects of proration in determining the life of individual fields. Data for the period 1900–1931 presented by Snider give some indication of a drop in the average natural life of pools prior to proration efforts.[71]

Among States the life of present known reserves is related somewhat to the history of production. For example, the oil resources of Oklahoma were exploited rapidly after the development of the Glenn pool in 1906, with the result that the estimated life of proven reserves in terms of 1937 production was less for Oklahoma than for any other major producing State (table 8). Note that the maximum estimate, that of McCoy, was only 6.5 years, whereas that of the *Oil and Gas Journal* was 4.2 years. In terms of the present rate of withdrawal from reserves, Texas and California are in favorable positions.[72] The American Petroleum Institute reserve estimate at the first of 1938 indicated a life of 16.1 years for known Texas reserves, and for California, a life of 12.8 years. Moreover, since January 1938, important discoveries have been made in both States. Recent discoveries probably also will extend the estimated life of Louisiana reserves. Oklahoma is unfortunate not only in having a low estimated life of reserves at the beginning of 1938 but also in the lack of any outstanding discoveries since then. The discovery of sizable reserves in western Kansas in the past few years has extended the prospective life of reserves in that State. A suggestion has been made that the States or the Federal Government should regulate the production in each State on the basis of the ratio of reserves to current production, and specifically that production should be restricted each year to one-eleventh or some such fraction of known reserves.[73] Such regulation would be very difficult to apply. At the present time it would limit production mainly to Texas and California and require the closing of wells in nearly all other States until additional reserves were discovered. Since new reserves are found mainly in connection with the rise in production, such a restriction would necessitate heavy investment in exploratory activity and also considerable capital investment in proved reserves. Yet some method of restricting increases in output in States with a short life of reserves may be desirable, since it probably would lead to less waste of capital in production and refining facilities.

TABLE 8.—*Years' supply of crude petroleum in the United States, by States, Jan. 1, 1938*

[Based on 1937 production and reserve estimates as of Jan. 1, 1938]

	American Petroleum Institute estimate	*Oil and Gas Journal* estimate	McCoy estimate
Arkansas	16.4	6.8	11.8
California	12.8	12.5	11.3
Colorado	12.8	13.2	9.4
Illinois	5.5	5.3	6.7
Indiana	3.2	3.8	13.3
Kansas	8.5	9.0	10.6
Kentucky	7.0	5.6	5.5
Louisiana	7.9	6.6	7.7
Michigan	3.1	2.7	4.9
Montana	18.9	9.0	8.2
New Mexico	14.1	16.1	11.1
New York	11.1	4.7	7.3
Ohio	8.0	5.2	10.1
Oklahoma	5.3	4.2	6.5
Pennsylvania	15.0	9.8	15.7
Texas	16.1	13.4	11.5
West Virginia	7.3	3.5	6.5
Wyoming	14.2	16.7	11.5
United States	12.1	10.6	10.1

Source: U. S. Bureau of Mines, *Minerals Yearbook 1938*, p. 823; *American Petroleum Institute Quarterly*, April 1938, p. 12; *Oil and Gas Journal*, Jan. 27, 1938, p. 39; Alex W. McCoy, *Estimate of Petroleum Reserves, United States*, Ponca City, Okla., January 1938.

The problem of adequacy of reserves in California is somewhat different from that of other oil regions because of its isolation. In the main, California supplies of oil are consumed on the west coast or are exported. Occasionally, when the eastern seaboard price of crude is comparatively high, tanker shipments are made by way of the Panama Canal. In 1936, however, aside from the average daily exports of 46,000 barrels, California crude was consumed almost entirely in that and nearby States. It has been estimated that California's reserves approximate 3 billion barrels, or enough for about a 20-year supply. If foreign shipments were eliminated, oil production could be reduced to Pacific coast requirements and the reserve last for 25 years.[74]

[70a] Harry F. Simons, "Conservation Law for Illinois Will Probably Be Delayed," *Oil and Gas Journal*, March 30, 1939, pp. 55–56; also *ibid.*, January 12, 1939, pp. 25–26.

[71] *Ibid.*; McCoy, *loc. cit.*, presents for each pool in the major oil-producing States the year of discovery, total production to January 1, 1937, the reserve estimate as of January 1, 1937, and estimated total ultimate recovery. Many pools which accounted for considerable production are completely or almost exhausted.

[72] See, however, F. E. Minshall, "Future Supply of Oil in California," *A. I. M. M. E., Pet. Dev. Tech., 1937*, p. 265; and *A. I. M. M. E., Pet. Dev. Tech., 1937*, pp. 255–256.

[73] W. V. Howard, "Known Reserves Must Increase Rapidly to Keep Pace with Future Demands," *Oil and Gas Journal*, February 10, 1938, pp. 12, 14. The author apparently prefers that the ratio of production to reserves be based on a 3-year average of production.

[74] *A. I. M. M. E., Pet. Dev. Tech., 1937*, pp. 255–56.

With respect to natural gas, it is even more logical to make a comparison between reserves in California and local requirements. None of the gas is shipped out of the State.

Among the various regions producing natural gas, estimates of reserves indicate a life of approximately 33 years for the midcontinent and Gulf coast section.[75] The life of reserves in the Appalachian region and in California is estimated to be somewhat less.[76]

Adequacy of Reserves to Meet Future Demand

Among outsiders there is an impression that an estimate of reserves is merely a conservative guess of how much oil can be produced. In the past the public has been faced with estimates which seem to indicate a threatening shortage of petroleum and its products within a decade or so. Such estimates often have been followed by the discovery of flush oil pools which have led to what appeared to be serious overproduction of crude oil. As a result people have become skeptical that there ever will be an end to oil and gas reserves. In estimating the possibilities of new discoveries, however, one must guard against such assertions that "there has been and always will be enough petroleum to meet demand." Perhaps the general impression results from a misunderstanding of what petroleum engineers and geologists mean by estimates of reserves. As already noted, reserve estimates usually refer only to proven supplies—that is, to those underground reserves which have been discovered, and only to that portion of the resource estimated as recoverable by present methods. Note also that taxation makes for conservative estimates of reserves.

There appears to be considerable contradiction in the views within the industry on the subject of oil reserves. While engineers are currently estimating known reserves as sufficient for only a few years of consumption, the major firms in the industry appear confident that search in unexplored territory will reveal many new oil pools and that deeper productive strata underlie many of our older producing fields. Perhaps by "scarcity" the geologist refers primarily to frequency of discovery rather than to volume of the oil reserve itself.[77] A drop in the rate of discovery might indicate an approach to the limit of the amount of oil available from all underground reservoirs, but it is largely due to other factors.

Executives in the oil and gas industry are usually optimistic concerning the adequacy of reserves. For example, Harry F. Sinclair stated several years ago that domestic reserves would supply the Nation's demand for oil for the next 100 to 500 years.[78] Axtell J. Byles, president of the American Petroleum Institute, has recently stated that proven and undiscovered reserves would be adequate to supply needs "in abundance for an indeterminable time to come." [79]

On the other hand, many geologists and Government officials have been concerned over a possible petroleum shortage. In setting up the Federal Oil Conservation Board in 1924, President Coolidge expressed this attitude.[80] Secretary of the Interior, Harold L. Ickes, in 1934, expressed alarm that there would be an oil shortage here much sooner than abroad.[81] Perhaps the most pessimistic viewpoint is that taken by Governor E. W. Marland, of Oklahoma, who has held that the present known supply will last less than 4 years. In fact, he expects a serious shortage by 1942, unless large reserves are discovered in the meantime.[82]

Governor Marland's predictions are based, in large part, on a report made to him by Alex W. McCoy, a petroleum geologist. McCoy stated in January 1938 "that the present drilled reserve is capable of producing sufficient oil to meet the expected demand until November 1941." [83] Moreover, he held that "the discovery necessary throughout 1938 to 1942, inclusive, must approximate 6,000,000,000 barrels in order for the present known reserve and this discovery to produce sufficient crude oil to meet the expected demand after 1943." [84] After 1938, McCoy expects the average cost of production to rise from an average of $1.11 for the period between 1924 and 1938 to $1.89 for the period 1938 to 1957, inclusive.[85] Garfias has indicated that he expects a petroleum shortage by 1949.[86] Hale B. Soyster, of the United States Geological Survey, in 1934 stated that the estimated known reserves would last not more than 15 years, assuming that the oil could be recovered within that period. He further stated that although new fields would be discovered, the rate of discovery would slow down.[87] Brooks and Snider have expressed the view that a shortage will occur between 1940 and 1943.[88] On the other hand, Wasson expects no petroleum shortage for several decades.[89] At any rate, the years after 1930 have shown comparatively small additions to known reserves in terms of the rate of consumption of crude oil.

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[75] Williams, *loc. cit.*

[76] Davis, *loc. cit.*

[77] H. J. Wasson, "Chronological Aspects of American Oil-Reserve Replenishment with a Note on the Contemporary Situation," *A. I. M. M. E., Pet. Dev. Tech., 1937*, p. 1127; Garfias and Whetsel, *A. I. M. M. E., Pet. Dev. Tech., 1936*, p. 211.

[78] *Petroleum Investigation, 1934*, p. 2507; Samuel B. Pettengill, *Hot Oil*, New York, 1936, p. 11.

[79] *Oil and Gas Journal*, March 3, 1938, p. 32; Pogue, *op. cit.*, p. 15.

[80] Federal Oil Conservation Board, *Report I to the President of the United States*, September 1926, pp. 1–2.

[81] *Petroleum Investigation, 1934*, p. 167.

[82] "By 1942, the oil obtained from all the present drilled reserves, all the present known reserves not yet drilled, and all the new reserves expected to be discovered in 1938, 1939, 1940, and 1941 will be needed to meet the demand for that year." *Oil and Gas Journal*, January 29, 1938, p. 59.

[83] McCoy, *op. cit.*, p. 12.

[84] *Ibid.*, p. 13.

[85] *Ibid.*, pp. 16, 18.

[86] Garfias, *A. I. M. M. E., Pet. Dev. Tech., 1935*, p. 244. See also Garfias and Whetsel, *Science of Petroleum*, 1938, I, 532.

[87] *Petroleum Investigation, 1934*, pp. 14–18.

[88] *Op. cit.*, p. 18. See also Snider, *op. cit.*, p. 86.

In order to maintain a rising volume of petroleum production many new fields are required. Moreover, some of them must be big fields of flush production, and such fields must be discovered every year or so. A flush pool of the magnitude of the Oklahoma City or East Texas type appears to be required every few years. Production has grown so much in the last 20 years that at the end of 1937 no one field in the United States had produced, in its entire history, the equivalent of the 1937 output. Only the great East Texas field with accumulated production of 1.13 billion barrels at that time had approached the 1937 domestic output of 1.28 billion barrels.[90] With the rapid rise in consumption it is no longer easy to find a field which within a year or two can supply as much as 5 percent of the annual requirements. During the first part of the twentieth century many of the new fields were that important, but by 1929 few of the great new fields exceeded 5 percent of the national output. In no year since then has the output of any new field except the East Texas field exceeded 5 percent of the national production. The ultimate production of a new field in relation to production of petroleum during the year of its discovery has been defined by Snider as the "replacement factor" of that reserve. Of 30 major fields—15 discovered prior to 1913 and 15 discovered from 1913 through 1931—Snider found that the earlier fields each probably will attain a replacement factor of 1, whereas not more than 6 of the later 15 have any prospect of doing so.[91]

At the present time exploratory efforts are meeting with increasing difficulty. Reserves are being enlarged more by the extension of known fields than by entirely new discoveries.[92] Although much confidence is being placed in the possibility of additional discoveries by deep drilling, it must be noted that there is a limit to the depth at which oil can be discovered, partly because of the technical limits to drilling and mainly because reservoirs deeper than about 13,000 feet are more likely to contain natural gas or, at the most, a light gravity distillate and not crude oil.[93] Unfortunately, when these deep wells cease flowing they cannot be pumped.

W. V. Howard has estimated the inability of the reserves to keep pace with demand by comparing how much additional supplies would have been needed to maintain a previous ratio of production to reserves. For example, at the end of 1936 the *Oil and Gas Journal* estimated reserves of 11.4 years' supply. In terms of the 1937 production and the reserves at the end of that year, the life was estimated to be 10.7 years. To have maintained the old ratio would have required additional discoveries in 1937 of 0.9 billion barrels, or a total for the year of 3.2 billion barrels. Moreover, Howard estimated that if an 11 years' supply of reserves was to be maintained, new reserves of between 2.5 billion and 3 billion barrels needed to be discovered in 1938.[94] Actual discoveries and extensions, including revisions, were estimated by the *Oil and Gas Journal* at 2.1 billion barrels and by the American Petroleum Institute Committee at 3.1 billion barrels.

If discoveries in the next few years should prove deficient, the adequacy of reserves to meet future demand would depend on the difficulty of producing fast enough from the present reserve. As already noted, nearly half of the recoverable oil in the reservoir is obtained during the first few years of flush production and the remainder at a decreasing rate. This slowing down of the rate of recovery at the later stages of life of a field is in part an indication of present technical limitations in the extraction of crude. Garfias and Whetsel have pointed out that, with a yearly world demand of about 1.7 billion barrels for the decade following 1935 and with the proven world reserves of 23 billion barrels as of January 1, 1936, additional flush production from new reserves of about 15 billion barrels would be needed during the decade.[95]

The possibility of exhausting oil and gas reserves depends in part, of course, on future trends of consumption, including trends in efficiencies of use and possible changes in the nature of demand which might affect the price of gasoline. These considerations are treated in chapters 3 and 4. It should be noted here, however, that threatened exhaustion is being postponed by the improvement of operating methods and wider adoption of the better techniques of recovery. On the other hand, a continued rise in automobile registrations may more than offset the savings realized by efficiency of use. Long before oil reserves are exhausted, prices of the major petroleum products will begin to rise. In 1935

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[89] Wasson, *op. cit.*, p. 227; note also the opinion of E. B. O'Rourke of Ohio State University, *Oil and Gas Journal*, April 21, 1938, p. 26.

[90] *Minerals Yearbook, 1938*, pp. 815, 824.

[91] Snider, *op. cit.*, pp. 72–78. "The ultimate production of a field divided by the total production of the United States during the year of its discovery shows the number of times the withdrawal from the reserves during that year was replaced by the discovery of that field, and this number may be called the replacement factor."

[92] In 1938, according to the A. P. I., extensions and revisions exceeded discoveries in new pools and new producing horizons in Texas, Louisiana, California, Oklahoma, and New Mexico, but not in Kansas, Illinois, Arkansas, and Michigan. *Oil and Gas Journal*, March 2, 1939, p. 21.

[93] Eugene A. Stephenson, "Behavior of Contents of High-Pressure Reservoirs," *A. I. M. M. E., Pet. Dev. Tech., 1938*, pp. 189–197; also see Pratt, *op. cit.*, p. 48, and *Oil Weekly*, August 29, 1938, p. 28.

[94] W. V. Howard, *loc. cit.*

[95] *Op. cit.*, p. 533.

Brooks and Snider[96] suggested that within the next decade the relative scarcity would create a rise in prices at the present demand and that an increasing demand might bring about a shortage in a few years. In that event, the operation of the industry would doubtless place more emphasis on higher priced products, notably lubricants, and the motor vehicle industry might have to find other sources of extra fuel supplies. If the price of gasoline rises above the costs of making fuel from shale or from coal, these materials will begin to supersede gasoline. Costs of making fuel by the hydrogenation of coal are estimated upwards from 12 cents a gallon.[97] Consequently, the shortage of crude oil would have to become severe before substitutes could be called upon. Although it cannot be stated with any certainty when exhaustion will become a problem in the United States, it is clear that the problem will appear in the United States before it does in the balance of the world. We have produced a larger percentage of our reserves; we are now using our reserves at a faster rate than the rest of the world; and probably we have discovered a much larger percentage of our total possible reserves because of the more intensive search for oil in this country.[98] The United States now accounts for approximately 60 percent of the world's consumption but only 50 percent of the proven reserves. Secretary of the Interior Ickes has stated that we are using our oil reserves about three times as rapidly as the rest of the world.[99] At the present time, it appears reasonably certain that Oklahoma will exhaust her reserves before California does and that in the future an increasing percentage of the total amount of reserves will be accounted for by Texas, which already contains half the national supply. Exhaustion of natural gas probably will not become a problem for two decades, although much depends on the restriction of consumption to the more economical uses. The great reserves of Texas, Oklahoma, Kansas, Louisiana, and New Mexico probably will be called on to a greater extent in the future to supply the consumers in the midwestern section of the country and perhaps for centers of consumption as far east as the Atlantic seaboard.

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[96] *Op. cit.*, p. 18.

[97] The figure of 12 cents per gallon was given by President Farrish of the Standard Oil Co. of New Jersey; *Petroleum Investigation, 1934*, pp. 739, 748. A similar estimate was reported by C. C. Wright and A. W. Gauger, *Progress Report on Coal Hydrogenation*, Technical Report No 2, Bituminous Coal Research, Inc., October 1936, pp. 13 14. On the other hand, the experimental station of the United States Bureau of Mines at Pittsburgh reports that the retail price of substitute fuel would be two or three times that of gasoline; report of station, September 1938.

[98] Swanson, *loc. cit.*; Garfias and Whetsel, *op. cit.*, p. 532.

[99] *Petroleum Investigation, 1934*, p. 167; Pettengill, *op. cit.*, p. 10; also H. L. Ickes, "Oil and the World We Live In," address before the Independent Petroleum Association, Houston, Texas, October 15, 1937.

CHAPTER 3.—PRODUCTION TRENDS AND TECHNOLOGICAL ADVANCES

Production Trends

National Trends

Production of crude oil in the United States followed an upward trend to 1929 and after the great depression reached a new peak in 1937 of, roughly, 1.3 billion barrels.[1] Somewhat more than 50 percent of the 21 billion barrels produced since 1859 was obtained in the 11 years ended with 1938, and the last 16 years have accounted for, roughly, 70 percent of the total.[2] The same growth is evident in the production of natural gas. Production reached a peak of 2.4 trillion cubic feet in 1937.[3] Production of natural gas in 1906 was slightly less than one-sixth of the 1937 production.

Although petroleum production for the entire United States follows an upward trend, production in individual fields nearly always reaches a peak early in the life of the pool and falls off sharply thereafter. For instance, the Glenn oil pool contributed 11.8 percent of the United States total in the second year of its life, 11.5 percent in the third, and declined steadily to 0.2 percent in the twenty-fifth year.[4] This is shown more clearly if we look at the percentage of peak-year production in later years. The Glenn pool, discovered in late 1905, reached its maximum output in 1908. In the year following it produced 92 percent of the peak; in the second year following, 93 percent; and in the third year, 79 percent. In 1928 it reached only 10 percent of the maximum. In many newer fields much sharper declines follow peak production. For example, the Wortham pool at its peak in 1925 contributed 16,838,000 barrels of crude and in 1926 only 19 percent of that amount. In the third year after its peak it produced only 4 percent of the record amount and by 1931 only 1 percent.[5] In Arkansas, the Smackover field shows a precipitous drop after 1925, when it produced 74,383,000 barrels of crude. Its production declined in 1926 to 71 percent of the peak; in the next year a further decline reduced production to only 43 percent of the peak.[6] By 1937 it produced only 9 percent of the 1925 volume. In 1927 deep drilling in the Spindletop field in Texas produced a maximum output of 20,751,000 barrels. In the next year production dropped to 68 percent and continued to fall off until, in 1936, it produced only 4 percent of its peak production.[7]

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[1] 1,279,160,000 barrels. *Annual Petroleum Statement No. P 177*, U. S. Department of the Interior, Bureau of Mines, November 10, 1938.

[2] For production through 1937, see pt. two, sec. I, chap. 2, fig. 5 of this report; and H. M. Stalcup, "What the Oil Industry Is Doing About Conservation," *Oil and Gas Journal*, May 19, 1938, p. 50. Production for 1938 has been estimated at 1.2 billion barrels; *Oil and Gas Journal*, January 26, 1939, p. 73.

[3] 2,447,620,000 cubic feet. U. S. Bureau of Mines, *Natural Gas Consumption Sets New Record in 1937*, Mineral Market Reports, No. M. M. S. 682, December 13, 1938, p. 1.

[4] L. C. Snider, "A Comparison of Old and New Fields," *A. I. M. M. E., Pet. Dev. Tech., 1933*, p. 79.

[5] *Ibid.*, pp. 82 83.

Similarly, many gas fields are very short-lived. The Big Moses gas well in Tyler County, W. Va., has long since been forgotten, but in the early days of the industry it was one of the greatest of all wells, producing 35 million cubic feet a day.[8]

From the point of view of costs this decline in production is important. Flush production results in waste of reservoir energy, and high-cost secondary recovery methods must soon be resorted to in order to retrieve the oil left in the ground. Proof of this is shown in a report which shows average operating expense per barrel of oil produced to vary from 28 cents in the midcontinent to 83 cents in the eastern division, where oil is mainly produced through secondary recovery.[9] As production declines the average cost per barrel goes up, often resulting in early abandonment of wells. Therefore it is desirable to restrict production from the beginning to a level consistent with maximum recovery efficiency.

Regional Trends and Geographic Shifts

Today the calculated centers of oil and gas production are far from their original location in western Pennsylvania. According to F. G. Tryon and L. N. Plein, 20 years after the Drake well was completed the center of production was still in Pennsylvania. By 1889, however, the center had moved to northeastern Ohio; a decade later to a point close to the Indiana border; and between 1900 and 1910 there was a spectacular move of almost a thousand miles to central Kansas. In recent years the movement has been reversed, and the calculated center of crude-oil production between 1929 and 1935 shifted from northeastern New Mexico to the Texas Panhandle (fig. 3).[10]

A comparison of the leading producing States at different times indicates the same shift from the East to the West and the South. Until 1895 Pennsylvania was the leading State; in fact, between 1859 and 1875 Pennsylvania was practically the only producing State. In 1895 Ohio outranked Pennsylvania and remained the leading State until California surpassed it in 1903. California remained in the lead until 1915, at which time first rank in production went to Oklahoma, where it stayed until 1919. Then Oklahoma and California began to share the lead, California having it until 1920, Oklahoma until 1923, California again until 1927, and Oklahoma in 1927. Then Texas took the lead, with the discovery of the Hendricks and Yates pools, and since the development of the East Texas field it has kept far ahead of the other States (table 9).

TABLE 9.—*Peak production years for leading oil producing States in the United States, 1859–1937*

State	Peak year	Production	
		Thousands of barrels	Percent of United States total
New York	1882	6, 685	22
Pennsylvania	1891	31, 424	57
Ohio	1896	23, 941	39
West Virginia	1900	16, 196	25
Indiana	1904	11, 339	10
Illinois	1908	33, 686	19
Wyoming	1923	44, 785	6
Arkansas	1925	77, 398	10
Oklahoma	1927	277, 775	31
California	1929	292, 534	29
Michigan	1937	15, 928	1
New Mexico	1937	38, 797	3
Louisiana	1937	90, 510	7
Kansas	1937	70, 761	6
Texas	1937	510, 732	40

Source: U. S. Bureau of Mines, *Minerals Yearbook, 1937*, pp. 1008-1009; *Minerals Yearbook, 1938*, p. 848.

In the last 20 years of the nineteenth century, Pennsylvania, New York, and Ohio were the leading producers of oil. In their respective peak production years, Pennsylvania (1891) produced 57 percent of the total for the country, Ohio (1896) 39 percent, and New York (1882) 22 percent. In the first decade of the twentieth century, West Virginia, Illinois, and Indiana reached their peaks. West Virginia reached its peak output in 1902, when it produced 16 percent of the national total. In 1904 Indiana production attained its maximum, which constituted 9 percent of the total, while Illinois in her peak year, 1908, contributed 19 percent (fig. 5).

"In 1900 considerably more than half of the national requirements of crude petroleum came from the Appalachian fields, slightly more than a third from the Lima-northeastern Indiana-Michigan field, and the small remainder from California and the Gulf Coast fields. * * * The Appalachian field's share of the total in 1935 was 3.2 percent, and only 2.2 percent was furnished by the Lima-northeastern Indiana-Michigan fields."[11] Today, Texas is far in the lead, having pro-

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[6] *Ibid.*

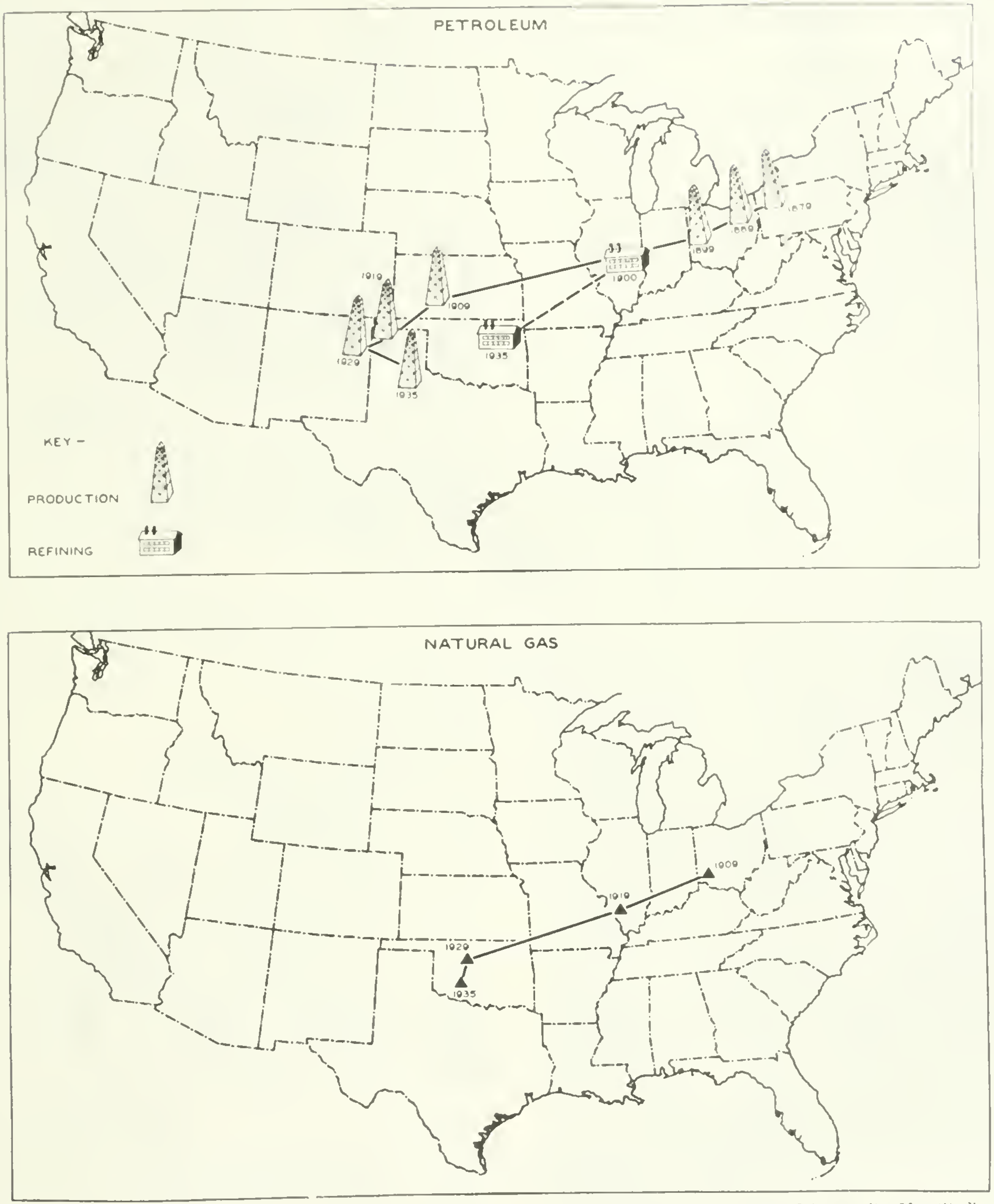
[7] *Minerals Yearbook, 1937*, p. 1022; *Minerals Yearbook, 1938*, p. 834.

[8] O. E. Kiessling, H. O. Rogers, G. R. Hopkins, and Others. *Technology, Employment, and Output-Per-Man in Petroleum and Natural-Gas Production*, National Research Project W. P. A. Report E–10, 1939 (in press), ch. III.

[9] Figures represent averages for the 3-year period, 1927–30; Petroleum Administrative Board, *Preliminary Report on A Survey of Crude Petroleum*, "Cost of Production for the Years 1931–33 and Comparison with Years 1927–30," Washington, 1934, pp. 8–9.

[10] Kiessling, *et al.*, *op. cit.*, ch. III.

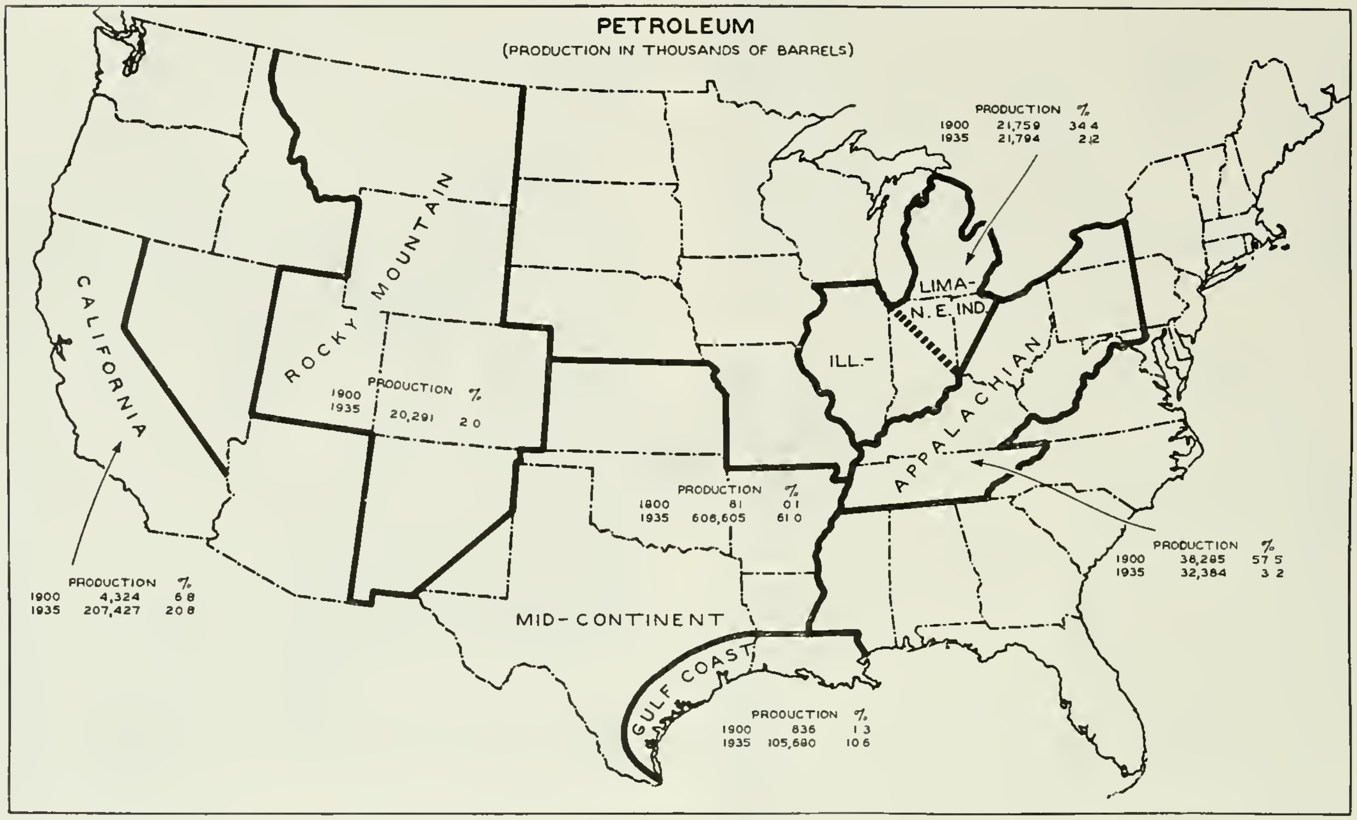
[11] *Ibid.*

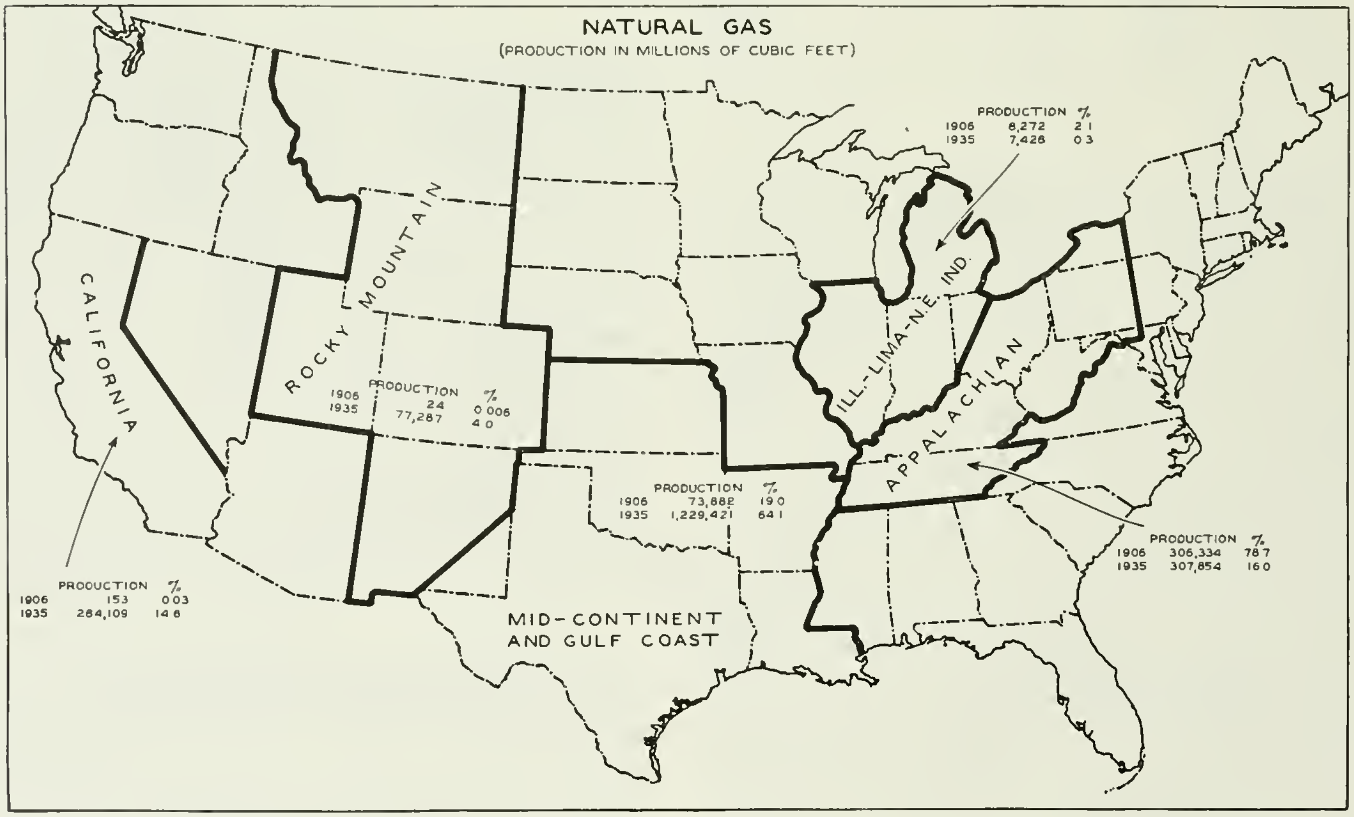


Hopkins and Rogers
U. S. Bureau of Mines

Mineral Technology and Output Per Man Studies
W. P. A.—National Research Project

FIGURE 3.—Calculated Centers of Petroleum and Natural Gas Production.


PETROLEUM
(PRODUCTION IN THOUSANDS OF BARRELS)
CALIFORNIA
ROCKY MOUNTAIN
MID-CONTINENT
GULF COAST
ILL.-
LIMA-N. E. IND.
APPALACHIAN
PRODUCTION % 1900 4,324 6 8 1935 207,427 20 8
PRODUCTION % 1900 1935 20,291 2 0
PRODUCTION % 1900 81 0 1 1935 606,605 61 0
PRODUCTION % 1900 836 1 3 1935 105,680 10 6
PRODUCTION % 1900 21,759 34 4 1935 21,794 2.2
PRODUCTION % 1900 38,285 57 5 1935 32,384 3 2


NATURAL GAS
(PRODUCTION IN MILLIONS OF CUBIC FEET)
CALIFORNIA
ROCKY MOUNTAIN
MID-CONTINENT AND GULF COAST
ILL.-LIMA-N.E. IND.
APPALACHIAN
PRODUCTION % 1906 153 0 03 1935 284,109 14 8
PRODUCTION % 1906 24 0 006 1935 77,287 4 0
PRODUCTION % 1906 73,882 19 0 1935 1,229,421 64 1
PRODUCTION % 1906 8,272 2 1 1935 7,428 0 3
PRODUCTION % 1906 306,334 78 7 1935 307,854 16 0

HOPKINS AND ROGERS
U. S. BUREAU OF MINES

MINERAL TECHNOLOGY AND OUTPUT PER MAN STUDIES
WPA-NATIONAL RESEARCH PROJECT

FIGURE 4.—Relative Importance of Major Petroleum and Natural Gas Producing Districts in 1906 and 1935.

duced 40 percent of the United States total in 1937 (table 10). California and Oklahoma almost tied for second place, with 18.7 percent of the United States total produced by the former and 17.9 percent by the latter. The three States produced an aggregate of 76.6 percent of United States production. Louisiana stepped up production and is now contributing a greater percentage than Kansas.[12]

A preliminary estimate of 1938 production indicates a somewhat different picture.[13] Although Texas and Kansas contributed slightly less to the Nation's total for 1938 and California and Louisiana slightly more, the significant changes were the rapid increase in Illinois and the marked decline in Oklahoma. While proration may account for some of the drop in Oklahoma, the main reason probably was lack of new development.[14] The outlook for the future indicates further shifts in production. Texas probably will have to shoulder much of the deficiency in Oklahoma production, a material drop in which now seems imminent.[15] Because of deeper drilling, we may obtain increased production from Louisiana, Illinois, Michigan, Kansas, and Wyoming.

TABLE 10. *Production of crude petroleum in the United States and percentage of total, by principal States, 1937*

	Production	
	Thousands of barrels	Percent of United States total
Texas	510,732	40.0
California	238,521	18.7
Oklahoma	228,924	17.9
Louisiana	90,510	7.1
Kansas	70,761	5.5
New Mexico	38,797	3.0
All other	99,408	7.8
Total United States	1,277,653	100.0

Source: U. S. Bureau of Mines, *Minerals Yearbook, 1938*, p. 824.

In natural gas, also, there have been shifts in production. Although in 1909 the calculated center of natural-gas production was in southeastern Ohio, in 1919 it had shifted to southern Illinois, and at present it is in central Oklahoma.[16] In the earliest period of natural-gas production Pennsylvania was the leading State. West Virginia, in 1909, stepped up to first place and remained far in the lead until 1923, at which time it produced 20.2 percent of the country's total. In the next year Oklahoma passed West Virginia to become the leading producer, and at the same time Pennsylvania receded from fourth to sixth place.[17] These changes marked the passing supremacy of eastern States in the production of natural gas and a closer agreement between the ranking of States according to natural-gas production and that according to oil production. In part the similarity resulted from the increased production of casing-head gas.[18] Oklahoma retained the lead through 1928, since which year Texas has outdistanced by far other gas-producing States. Several other States, including Arkansas, Colorado, Illinois, Indiana, Ohio, Wyoming, and Kansas, have witnessed a rise and fall in natural-gas production, although Kansas now appears to be climbing to a second peak. In Ohio production has remained comparatively steady. Other major producing States which have apparently not yet reached a peak are California, Kentucky, Montana, New Mexico, and Louisiana.[19] It is probably from these States and Texas that we may expect our future gas production.

PERCENTAGE OF TOTAL CRUDE PETROLEUM PRODUCTION IN THE UNITED STATES CONTRIBUTED BY EACH OF SIX LEADING PRODUCER STATES, 1891 – 1937

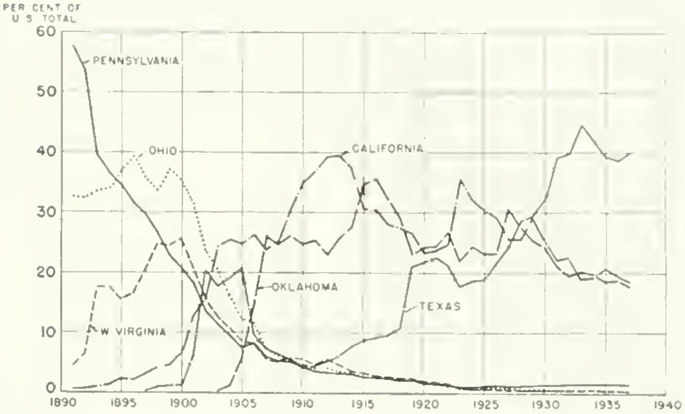


FIGURE 5.

Refinery activity also has moved to the Southwest. In the early stage of the industry refineries were located near the crude-oil fields in Pennsylvania and Ohio. In 1900 the calculated refining center was in central Illinois. With the development of pipe-line transportation, it was possible for refineries to be located in relation to the best economic distribution of products to their markets, yet only a fourth of the petroleum refinery capacity is now located in large industrial areas. The rise of the great Gulf Coast refining district was related in large measure to the existence of cheap water transport to the east coast and to foreign markets. In 1935 the calculated center of refining was in northeastern Oklahoma, in the same general territory as the center of oil production (fig. 3).[20]

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[12] In 1937, Louisiana produced 7.1 percent of the national total; Kansas, 5.5 percent; and New Mexico, 3 percent. Pennsylvania, Michigan, and Arkansas together produced less than 4 percent of the United States total.

[13] Production in the United States declined in 1938. Texas produced 39.2 percent of the total; California, 20.8 percent; Oklahoma, 14.1 percent; Louisiana, 7.9 percent; Kansas, 4.8 percent; New Mexico, 3.0 percent; and Illinois, 1.9 percent. As a result of new discoveries, Illinois produced 22.8 million barrels during 1938, in comparison with 7.4 million in 1937. Oklahoma's production, on the other hand, fell from 223.1 million barrels in 1937 to 169.3 million in 1938. James McIntyre, "Producers Meet Buyers' Demand," *Oil and Gas Journal*, January 26, 1939, p. 77.

[14] See p. 140 of this report.

[15] A. T. Shurick, "Significance of Latest Estimates of Oil Reserves; Situation in Key States," *Annalist*, Friday, December 3, 1937, p. 903.

[16] Kiessling, *et al., op. cit.*, ch. III.

[17] *Minerals Yearbook, 1937*, p. 1062.

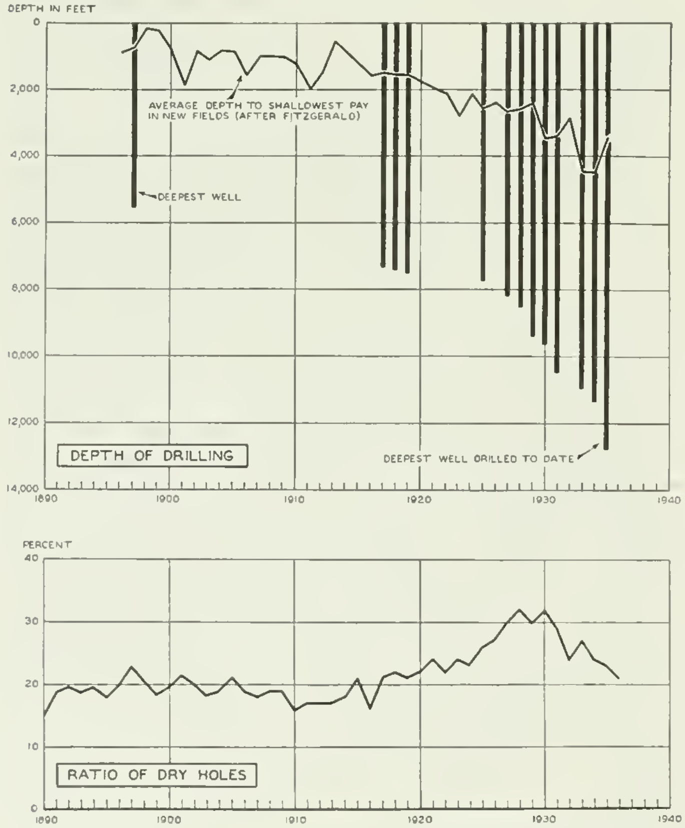
[18] Gas obtained from oil wells. *Minerals Resources of the United States, 1934*, pt. II, U. S. Bureau of Mines, p. 321.

[19] *Minerals Yearbook, 1937*, p. 1062.

The continuous movement from districts of old, partially depleted fields, where the reservoir energy has been exhausted, to new areas of flush, low-cost production has resulted in greater and greater difficulty in finding new areas. Also, it has involved the problem of moving the products from more distant sources of supply to major markets, especially in the populous East. The oil industry has applied itself readily to the solution of these problems.

Increasing Difficulty of Obtaining Supplies of Oil and Gas

The remainder of this chapter covers two subjects: First, the growing problems which the oil and gas industry is facing; and second, the technical improvements which have been made toward solving these difficulties.



HOPKINS AND ROGERS
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FIGURE 6.—Indicators of Increasing Physical Difficulty Encountered in Petroleum and Natural Gas Production.

Exploration

The life of oil and gas fields has been relatively short, partly owing to the rising demand for petroleum products. Since the practical exhaustion of a field necessitates the finding of a new one, there have been intensified efforts to locate new sources of supply. Although there were more discoveries in 1930 than in any other year,[21] and although discoveries of fields have continued, new reserves have little more than equaled production until 1937 and 1938, during which years nearly 4.3 billion barrels were added to known reserves.[22] These recent discoveries were made only after mounting expenditures for exploration and therefore also indicate the growing problem of locating new sources.

As shallower fields and more obvious areas are exploited, structures containing oil become more difficult to find. Haphazard drilling was successful as long as there were abundant surface indications where the oil could be found. Practically all discoveries made prior to the turn of the present century resulted from elementary surface indications or from random drilling.[23] In the period between 1901 and 1905, according to Pratt,[24] 70 percent of the major discoveries resulted from obvious evidences and 20 percent from purely random drilling, the remaining 10 percent being a result of geological exploration; whereas between 1930 and 1936 less than 3 percent of the million-barrel fields found were discovered otherwise than by scientific methods of search.[25] Not one pool was found between the years 1931 and 1935 as a result of drilling from obvious evidences.[26]

That oil was becoming more difficult to find is borne out by the increasing number of dry holes in relation to the number of well completions. There was a definite upward trend in the dry-hole index from 1880 until 1930 (fig. 6).[27] Although the drop in the index at this time may be explained in part by increased efficiency of discovery,[28] it has been influenced also by discourage-

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[20] Kiessling, *et al.*, *op. cit.*, ch. III.

[21] H. J. Wasson, "American Oil-Reserve Replenishment," *A. I. M. M. E., Pet. Dev. Tech., 1937*, p. 230.

[22] For net additions to reserves in 1937 and 1938, see *American Petroleum Institute Quarterly*, April 1938, p. 12, and *Oil and Gas Journal*, March 2, 1939, p. 21. The above figure refers to A. P. I. estimates of net additions to proved reserves—2.45 billion barrels in 1937 and 1.84 billion barrels in 1938.

[23] *Ibid.*, pp. 20–21.

[24] Wallace E. Pratt, "Discovery Rates in Oil Finding," *Oil and Gas Journal*, March 25, 1937, p. 46.

[25] Kiessling, *et al.*, *op. cit.*

[26] Pratt, *loc. cit.*

[27] The same is true of gas wells, from 1910, when figures were first available, to 1930, K. C. Heald, "Petroleum and Natural Gas," *Technological Trends and National Policy*, National Resources Committee, 1937, p. 146.

[28] *Ibid.*, p. 156.

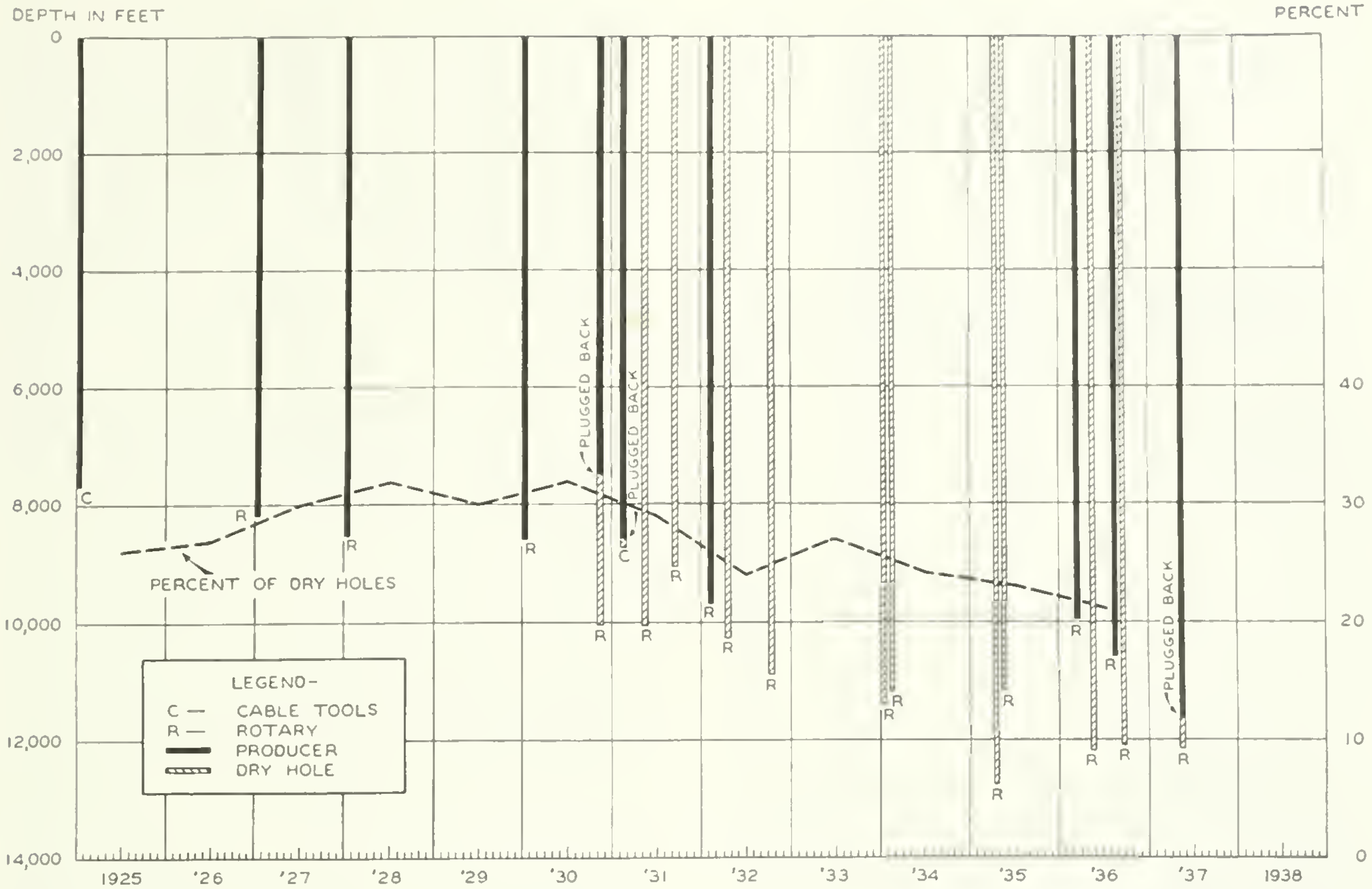

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FIGURE 6A.—Record of Increasing Depth of Drilling in the United States, 1925–37.

ment of random drilling, resulting from depressed prices and excessive production in proven areas, such as East Texas.

The increasing proportion of dry holes resulting from chance drilling and the rising expenses of searching for deeper oil horizons made the costs of random drilling almost prohibitive, and other methods of exploring had to be resorted to. Though newer scientific methods result in a higher percentage of oil discoveries, they require heavy expenditures. Consequently there has been a marked shift from independent wildcatting to large-company exploration.

No figures are available as to the cost of random drilling in the early development period, when surface indications were numerous. During the 3-year period 1934–36, geological discovery costs were estimated to be 2.24 cents a barrel, and geophysical costs for the same period amounted to 2.26 cents a barrel.[29] Although probably higher than in previous years, these figures still represent small percentages of the crude-oil price.

The amount of required investigation is augmented by the shifts from territories well defined through drilling and exploration to new sections of the country, for which few geological data are available.

Further discoveries by methods used in the past are becoming less probable. According to Pratt, new sources are likely to be pools of the East Texas type, "stratigraphic pools," where the reservoir control results from "shore-line" conditions. The search for pools of this type will require intensive study in stratigraphy, sedimentary petrography, and paleontology, with the continued aid of geophysics. It will amount, practically, to "core drilling" large areas to extreme depths. If the industry deliberately hunts for stratigraphic traps, Pratt says we may expect the recent decline in the relative number of dry holes to be arrested or reversed.[30]

Drilling

Pursuant to the search for new reserves, wells were sunk deeper and deeper, the greater depth of drilling being made possible by improvements in drilling tech-

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[29] Kiessling, *et al.*, *op. cit.*

[30] Pratt, *op. cit.*, pp. 48–50.

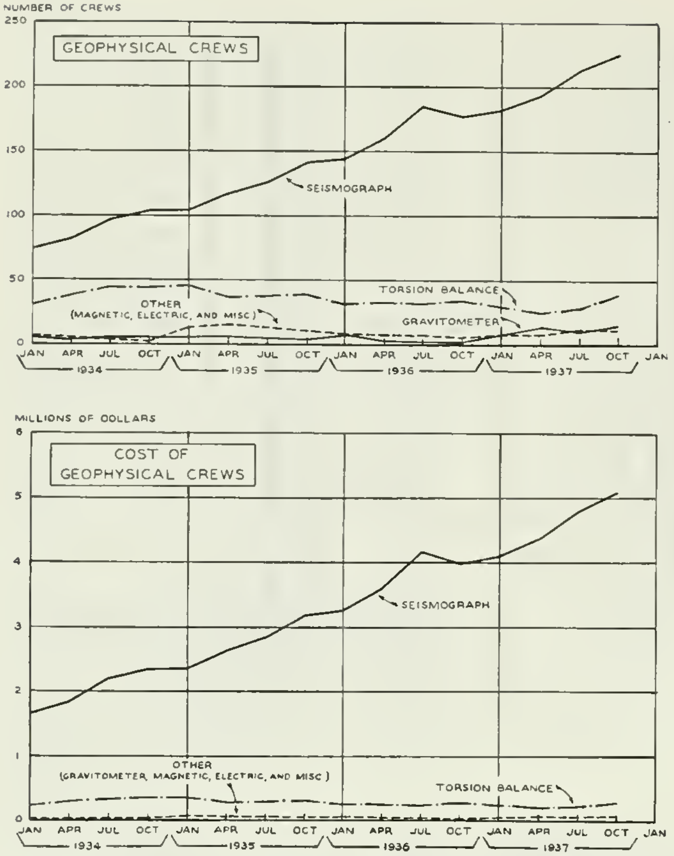

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FIGURE 7.—Number and Cost of Geophysical Crews Operating in the United States, 1934–37.

nique. With the exhaustion of the shallower fields in Pennsylvania, drilling activity shifted westward, and producers had to deal with more resistant formations at greater depths. Most of the Pennsylvania and New York wells in the early 1860's were only 100 feet deep. In later years the depth of the wells gradually increased. Yet most of the oil and gas in the Appalachian fields probably has been produced from an average depth of less than 1,800 feet.[31]

In 1890 the deepest well was somewhat less than 6,000 feet. Even by 1925 no hole had been drilled as far down as 8,000 feet (fig. 6).[32] In 1926 a total of 81 million feet was drilled to complete approximately 29,000 wells; 11 years later about the same number of wells involved almost 94 million feet of drilling (fig. 6).[33] At present many wells are being sunk more than 2 miles into the earth. The Gulf coast is the center of active deep drilling. At the end of 1937 there were 41 wells below 10,000 feet in the Texas and Louisiana Gulf coast districts, whereas in the first 6 months of 1938, 43 such deep tests were drilled, and 7 other tests were actively drilling below 10,000 feet on July 1.[34] The average depth of Texas producing wells today is 3⅓ times as great as it was in 1919.[35] Whereas Drake's well reached oil at 69½ feet,[36] the deepest drilled test [37] today, in Kern County, Calif., reached a depth of 15,004 feet before being plugged back.

With increased depths came further problems. Equipment capable of withstanding the stresses and strains involved in deep drilling had to be developed. Problems relatively simple in shallow holes, such as reaming or fishing for broken tools, become major problems in deep ones. High temperature at great depths introduced complications in pipe setting and cementing. Most difficult of all are problems of penetrating beds of material harder than drill steel and frequently of drilling through excessively soft formations.[38]

Still other problems center around the use of the rotary drill, which has largely replaced the cable-tool drill. The older method, successful for penetrating limestone and other hard-rock areas and for drilling in comparatively shallow fields, could not be adapted to pools at great depth beneath alluvial deposits and unconsolidated or semiconsolidated formations that cave easily.[39] One of the principal problems introduced by the rotary drilling method is that of crooked holes: and, although recent improvements permit straighter drilling, they frequently involve serious loss of time and great expense. There was also the serious danger of overlooking good oil sands until electrical logging was perfected. Another difficulty involves keeping the mud fluid at the correct density and viscosity. Controlling the pressure on the cutting tool in order to avoid damaging the drill pipe or injuring the bit is another problem of the rotary method.[40]

For the most part these difficulties have been met technically, but often at great expense. Drilling costs mount more or less geometrically as wells go deeper. The cost per thousand feet of hole ranges from $6,000 for the first thousand feet to $20,000 per thousand feet when the depth reaches 11,000 feet.[41] Shallow wells drilled in Pennsylvania and New York very early in the industry did not exceed a cost of $300, and up to 1880 the cost of wells drilled in Pennsylvania and West Virginia averaged about $1,200. In 1935, however, according to the reports received by the United States Bureau of Mines, the average cost per well was approximately $23,500. The great increase in expense undoubtedly was due mainly to the increased depth of drilling.[42] Mounting difficulties of reaching oil would have led to greater increases in costs had it not been for technical advances.

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[31] Ralph Arnold and William J. Kemnitzer, *Petroleum in the United States and Possessions*, New York, 1931, p. 62.

[32] *Ibid.*, p. 94; Kiessling, *et al.*, *op. cit.*, ch. VI.

[33] *Ibid.*, ch. V.

[34] Earl S. Post, "Gulf Coast is World's Most Active Deep Drilling Center," *Oil Weekly*, July 25, 1938, p. 103.

[35] "Average Depth of Texas Wells Three and a Third Greater," *Oil and Gas Journal*, July 7, 1938, p. 28.

[36] Kiessling, *et al.*, *op. cit.*, ch. VI.

[37] The deepest producing well, Fohs Oil. Co.'s Buckley No. 1, located in Terrebonne Parish, La., was produced from casing at 13,254–13,266 feet, L. G. E. Bignell, "Deep Wells in the United States," *Oil and Gas Journal*, September 8, 1938, p. 69. However, the well flowed for only a few weeks, so that, at the end of 1938, the Kern County well was the deepest producer.

[38] Kiessling, *et al.*, *op. cit.*, ch. VI; also see Heald, *loc. cit.*

[39] H. C. Miller and Ben E. Lindsly, U. S. Bureau of Mines, *Petroleum Investigation, 1934*, Hearings on H. Res. 441, 73d Cong., p. 1147.

[40] Kiessling, *et al.*, *op. cit.*, ch. VI.

[41] A thousand-foot well may cost $6,000, whereas the cost of an 11,000-foot well would average $143,000. *Oil and Gas Journal*, July 7, 1938, p. 28.

Production

Deep wells give rise to operating problems as well as drilling problems. By April 1938 there were at least 25 wells producing from levels below 10,000 feet.[43] Since an increasing proportion of production is likely to be from deep wells, certain difficulties need to be overcome. When natural flow ceases, there is no artificial method that will lift the oil from great depths except gas-lift, yet casings used for completing some deep wells will permit neither efficient gas-lift operations nor efficient natural flow after the first flush is over.[44] Furthermore, even from medium depths where pumping is possible, greater pressures and the existence of lighter oils combine to require refinements in the construction of pumps.[45]

The product obtained from deeply buried structures is predominantly a distillate in a gaseous phase; the deeper, the more gaseous.[46] Some investigators believe this is due to the retrograde condensation of oil associated with high pressures; so they think much light gravity crude will be left unrecovered because of condensation as pressure drops with production.[47] Further research is needed to determine the nature of hydrocarbons in such reservoirs and the conditions setting the point at which the liquid is driven into a gaseous state. Such information would have a bearing on the most practicable method and rate of flowing the wells.[48] The difficulty is that there is no way of observing what is happening underground while production is going on, although instruments developed in the past few years for bottom-hole sampling and pressure-recording have been very helpful.

Many other problems of production exist because so little is known about reservoir conditions and the migration of oil underground except from laboratory experiments. It is known that 100-percent recovery is never achieved. Some of the oil adheres to the reservoir rock and is not recoverable at all.

Oil capable of being moved is recoverable by natural or artificial drive. There are three sources of natural reservoir energy, namely, water, gas, and gravitation. The problem of maximum natural recovery is largely one of maximum efficiency in the utilization of this energy. The well-spacing problem and the use of reservoir energy are closely related.

Gas may be free in a gas cap or dissolved in the oil. Since free gas supplies energy in proportion to its amount and pressure,[49] it is desirable to retain it in the reservoir by avoiding the gas-cap area or by carrying the oil string down through that area. The problem lies in locating the gas-oil contact line.[50] The dissolved gas, besides providing energy by expansion, reduces the oil viscosity and surface tension. By maintenance of reservoir pressure the gas may be kept in solution with the oil. Moreover, if oil is produced too rapidly—at excessively high gas-oil ratios—the water pushing up against the oil may force its way into the spaces of least pressure and come to the well-bore in advance of the surrounding oil, thus trapping the oil by "coning."

The lithological properties of the reservoir rock increase resistance to flow. A greater part of the oil is held within the pores by capillarity,[51] while some is imprisoned by secondary influences, such as cementation. Wide variations in the porosity and permeability of the sand, in well diameters, and in formation pressures also complicate production methods. Indeed, the entire problem consists in determining and maintaining the most efficient rate of production, since too slow a rate may cause "slippage" of free gas and too rapid a rate in waste of reservoir energy.[52]

In operating gas fields the main problem is the decline in reservoir pressure as gas is removed from the ground.[53] Here, too, it is mainly a matter of controlling the rate of production and the spacing of wells.

Early production methods exhausted the reservoir energy before lifting much of the recoverable oil.

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[42] Costs at great depths mount because of more time required, more equipment, heavier and more expensive equipment, great hazards, breakage, loss of drilling equipment, and tedious and expensive delays. Kiessling, *et al.*, *op. cit.*

[43] *World's Deepest Wells Drilled Below 10,000 Feet*, wall chart published by Patterson-Ballagh Corporation, Ltd., April 1938.

[44] S. F. Shaw, "Gas-Lift—Modern Method for Production of Oil," *Oil and Gas Journal*, March 3, 1938, p. 44.

[45] Kiessling, *et al.*, *op. cit.*, ch. VI.

[46] Pratt, *op. cit.*, p. 48.

[47] Frank B. Taylor, "New Research Discoveries Point to Greater Recoveries," *Oil Weekly*, August 29, 1938, p. 28.

[48] *Ibid.*; also a statement by McGowan, *Oil and Gas Journal*, May 19, 1938, p. 38.

[49] Lyndon L. Foley, "Spacing of Oil Wells," *A. I. M. M. E., Pet. Dev. Tech.*, *1938*, pp. 16–22.

[50] P. P. Gregory, "Gas Caps. Their Determination and Significance," *A. I. M. M. E., Pet. Dev. Tech.*, *1938*, pp. 25–29.

[51] Capillarity results from surface tension (affected by gas in solution), cohesion of the oil, and the molecular attraction existing between the oil and mineral grain surfaces.

[52] Lester C. Uren, "Fundamental Principles Governing Drainage of Petroleum from its Reservoir Rock," *The Science of Petroleum*, London, 1938, I, 541.

[53] American Gas Association, "Organization of the Production, Transportation, and Distribution of Natural Gas and Manufactured Gas by Utilities," *Third World Power Conference*, sec. II, Paper No. 6, Washington, 1936, pp. 20–21.

George H. Ashley, State geologist of Pennsylvania, stated that only 20 percent or less had been recovered from the early Pennsylvania fields.[54] The oil remaining can be recovered only through expensive artificial means, which has tended to hold up the average cost of producing oil. For instance, in West Virginia, where all the wells may be classed as strippers, the net cost of producing a barrel of crude in 1937 was $2.30, whereas in the Louisiana Gulf coast, an area of large production per well per day, the cost per barrel in 1937 was only 71 cents.[55] Although reservoir conditions in the two districts originally were not altogether comparable, the net difference of $1.59 per barrel is attributable in part to the high cost of production where natural energy has been exhausted. Although technological advances have lowered the cost of production in recent years,[56] the drilling of deeper and newer strata is creating additional production problems for the industry.

Transportation and Storage

At the very outset of the industry oil was carried in small kegs by men on horseback or, as in the Oil Creek field, was loaded directly into barges and dugouts and floated down the river. As production extended back from Oil Creek transportation became a real problem. The only means of carrying the product to shipping points and refineries was by team and wagon over quickly turned up roads. For a distance of from 8 to 20 miles, $2.50 to $5.00 per barrel was paid for hauling the crude. Even after reaching Oil Creek much oil was lost owing to floods and poorly constructed equipment.[57]

Increased production over a wider territory led to the development of railroad tank cars and then pipe lines. Leakage in transit and fires were major troubles. Sometimes whole trains were ignited as a result of an explosion in one car. On the first pipe line the poorly constructed joints parted under pressure, and leakage was so great that the line was valueless. These difficulties were accentuated in pumping crude over mountains and across bodies of water.

As oil and gas production shifted away from centers of consumption, and since rail rates remained high and discriminating, it became necessary to construct longer pipe lines. New tools and new methods of putting the pipe together had to be developed. Later on, as refineries were located near crude, the moving of refined products raised further problems, including the handling of corrosive and highly volatile products.

In the natural-gas industry the transportation problem is even more difficult.[58] Largest reserves are located far from districts of large consumption, and pipeline transmission is the only way of reaching sizable markets.[59] Beginning with the 1920's production of casing-head gas increased, and much of this gas has been wasted because transport facilities have been lacking.[60] Yet rapid exhaustion of reserves and the great expense [61] of high-pressure transmission lines make uneconomical the laying of gas pipe line from many areas, especially from small isolated fields.

Major difficulties of transmitting gas relate to the necessary pressure. At first it was thought that gas was too expansive for transportation, that the pressure at the well might be gaged but not regulated, and that the volume at the terminus was indeterminable.[62] In addition, gas pressure drops as the gas travels; consequently, it was necessary to develop looping or step-up lines to maintain pressure.[63] Even now, some leakage is accepted as normal.[64]

Some of the obstacles to efficient transportation are likewise problems in storage. When oil was produced in small quantities, there were no storage difficulties. Small excesses were kept in crudely built wooden tubs or buckets. As the industry grew, barrels became inadequate and petroleum was stored in open pits or "sumps" with a consequent loss through seepage and evaporation of lighter constituents. Wooden tanks were tried next. But because of leakage from swelling or shrinkage of staves and because of the danger of fire, they were abandoned. Furthermore, among large containers fire could spread easily. Metal tanks were widely adopted, in spite of corrosion. Evaporation losses in open-top tanks were lessened, but not eliminated, by simple roofing. The fluctuating demand for various types of crude and the great variety of products handled have complicated segregation and required prompt changes in storage practices and pipe-line transportation.

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[54] *Petroleum Investigation, 1934*, p. 593.

[55] Estimates based essentially on 1936 figures of the U. S. Bureau of Mines; G. R. Hopkins and K. L. Stone, "Wide Variations Shown in Cost of Oil Production," *Oil and Gas Journal*, July 14, 1938, pp. 15–17. Although costs are high in West Virginia, they continue to produce because of advantages in place utility and the superior quality of the crude and also because operators neglect to consider their overhead costs.

[56] Petroleum Administrative Board, United States Department of the Interior, *Report on the Cost of Producing Crude Petroleum, 1935*, Washington, 1936, pp. 26–30; Joseph E. Pogue, "The Economic Structure of the American Petroleum Industry," *Third World Power Conference*, sec. II, Paper No. 5, Washington, 1936, pp. 21–22.

[57] It is estimated that 1,000,000 barrels of oil were lost on the water, *Oil and Gas Journal*, August 23, 1934, p. 21.

[58] "The main transmission pipe lines are the arteries of the natural-gas industry." Judson C. Dickerman, "Organization of the Production, Transportation, and Distribution of Natural and Manufactured Gas in the United States of America," *Third World Power Conference*, sec. II, Paper No. 6, Washington, 1936, p. 5.

[59] See pp. 131–132, 192, 193 of this report.

[60] Dickerman, *op. cit.*, p. 9.

[61] The actual cost of construction, exclusive of promoters' profits and questionable expenditures, of long pipe lines in recent years has been of the order of $30,000 to $60,000 per mile of main line, including compressor stations, telephone systems, etc., *ibid.*, p. 7.

[62] *Oil and Gas Journal*, August 23, 1934, p. 71.

[63] American Gas Association, *op. cit.*, p. 20.

[64] Some losses are inherent in the transmission of natural gas because of its fluid characteristics. The Bureau of Mines found that the leakage rate for welded lines in good condition was between 10,000 and 166,000 cubic feet per year for a mile. Federal Oil Conservation Board, *Report V to the President of the United States*, 1932, p. 55.

Since the beginning of the industry, production has continued to exceed consumption. In 1929 crude petroleum stocks reached a peak of 541 million barrels,[65] but have been declining since. Stocks of refined products also have been high. In 1937 the supply of finished gasoline on hand stood at a peak of 70 million barrels.[66] Although some surplus is essential, some is unintentionally accumulated as a result of fortuitous discovery and miscalculation of demand for refined products.

Refining

The principal objective of refining is to obtain maximum yields of high-value products at minimum refining costs. The problem is one of developing equipment and operations that will not only be adaptable to the wide variety of crudes but also will be flexible enough to meet changing demands for varying quantities and qualities of products.[67] At the same time there is the question of utilizing residual material.

For the first 50 years after Drake's discovery petroleum was refined primarily for kerosene, and the more volatile constituents of petroleum were dangerous byproducts.[68] In 1880, according to data from the United States Bureau of Census reports, kerosene represented 75 percent of the crude refined,[69] while the 12.5 percent of the crude unaccounted for probably represented mainly evaporation of the light fractions. Kerosene produced under these rudimentary methods was frequently inconsistent in quality and had an offensive odor.[70] When too much gasoline was left in it the kerosene sometimes exploded when used. Explosions and fires were reported in many of the first plants, and several of the plants never completed their first runs.

The properties of crudes differ greatly, and refinery operations must be adapted to these differences. Some Pennsylvania and Ohio crudes have only 0.05–0.08 percent sulphur and Lima-Indiana oil contains 0.55 percent, whereas in west Texas some crudes have nearly 3 percent sulphur and in the Santa Maria field in California tests have shown as much as 4.10 percent.[71] Crudes from the Texas Panhandle contain sulphurous compounds that break down on distillation and produce corrosive vapors.[72] California crudes have an asphaltic base and contain virtually no wax, whereas Appalachian crudes have a paraffin base. Many mid-continent oils contain varying amounts of wax and naphthenes. Consequently different refining processes were necessary in different parts of the country.

The development of the internal-combustion engine made it unnecessary to waste the lighter fractions of crude petroleum, and within a few years the demand for gasoline had grown so rapidly that it became the major refined product. At the same time electricity was supplanting kerosene as an illuminant.

During the war rapid growth of fuel consumption by automobiles and the high cost of crude made it desirable to vary the refining process so as to get an increasing yield of gasoline. The cracking process was introduced. With it came many technical problems. At first, equipment needed to be developed which would withstand the high temperatures and pressures required in the cracking process as well as the accompanying corrosion. One difficulty that seemed insurmountable was the deposit of carbon on the bottom of the still. Gum and discoloration in the gasoline have not yet been entirely eliminated. In recent years the quality of motor fuel has been stressed. Modern high-compression engines in automobiles and airplanes require fuel which has a higher octane rating or less tendency to knock in the motor.[73] More exacting specifications for other products have made the refining process difficult to coordinate.

Refining engineers have successfully applied themselves to the task of extracting gasoline from natural gas in order to save it and to prepare the gas for transportation. Natural gasoline, if left in the gas, condenses and chokes the pipe line.

Technical Advances

Difficulties described in the preceding discussion have been offset to a great extent by repeated technical improvements.

Exploration

The constantly changing technique applied to the search for crude has enabled the industry's supply to keep ahead of demand. At first explorers drilled where there were actual surface indications, but later came

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[65] Includes fuel oil in California. *Mineral Resources, 1929*, pt. II, p. 479.

[66] *Minerals Yearbook, 1938*, p. 874; also *Petroleum Facts and Figures, 1937*, American Petroleum Institute, New York, p. 123.

[67] Noel Robinson, "Organization of Production, Refining, and Distribution of Petroleum and Petroleum Products, History and Status of Petroleum Refining," *Third World Power Conference*, sec. II, Paper No. 5, Washington, 1936, p. 6.

[68] *Science of Petroleum*, I, ix–xii, preface.

[69] *Petroleum Facts and Figures, 1937*, p. 116.

[70] Kiessling, *et al.*, *op. cit.*, ch. VIII.

[71] Reports of the U. S. Bureau of Mines tabulated in Arnold and Kemnitzer, *op. cit.*, pp. 85, 136, 240, 417, 751.

[72] *Ibid.*, p. 207.

[73] The average compression ratio in automobile engines increased from approximately 4.6 in 1928 to 6.3 in 1938. W. W. Scheumann, "Automobile Engine Design Governs Modern Refinery Methods," *Oil and Gas Journal*, November 3, 1938, p. 12; *Oil and Gas Journal*, November 24, 1938, p. 30; W. T. Ziegenhain, "Aviation Gasoline," *Oil and Gas Journal*, November 3, 1938, p. 11.

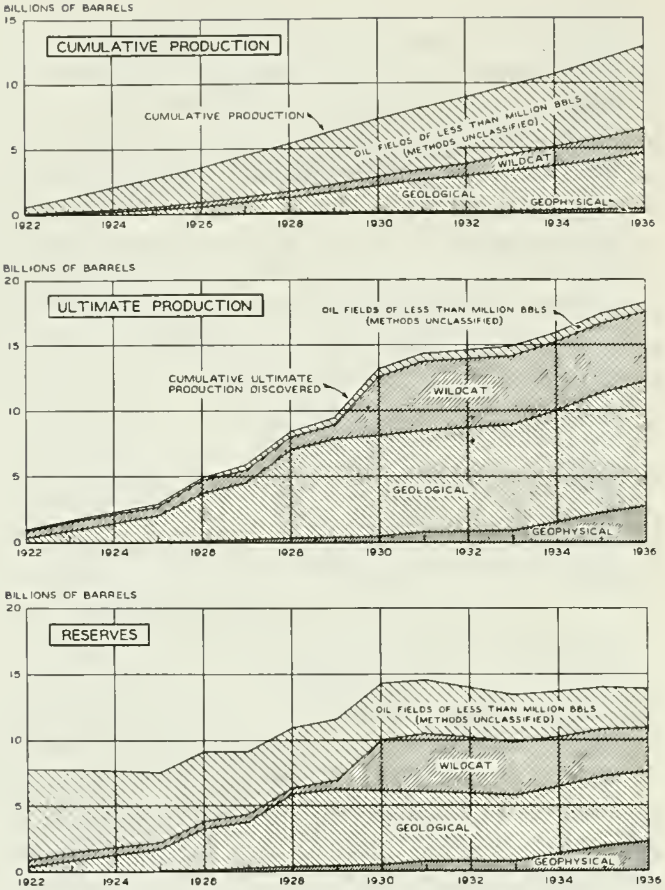

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FIGURE 7A.—Contributions of the Various Methods of Discovery to Cumulative Production, Ultimate Production, and Reserves, 1922–36.

to depend on scientific data. Geologic advances,[74] aided by improvements in the techniques of and facilities for mapping, indicated with increasing accuracy structures that might contain oil and/or gas. Within the last 15 years the science of physics has been used, and sensitive instruments have been developed which indicate something about conditions deep below the earth's surface. Geophysical methods alone, however, without drilling will not be effective in finding "stratigraphic traps," [75] one of the promising sources of future supply. Soil analysis, a recent development, may stimulate exploratory drilling in regions where geology indicates the presence of old shore lines or other favorable structural features. Since drilling in search of stratigraphic pools will amount practically to core drilling, the progress made in this technique, including electrical-logging and slim-hole drilling, assumes increasing importance.

Scientific methods of exploration have been successful in that enough discoveries and extensions have been made to keep ahead of a steadily mounting production. The decline in the proportion of dry holes from 32 percent in 1930 to 21 percent in 1937 is in part a reflection of advances in the finding technique.[76] The significance of progress in exploratory technique is again clear from an analysis of wildcat drilling.[77] During 1937 less than 800,000 feet were drilled in 138 discovery wells as contrasted with over 4 million feet in 1,002 dry holes. Only 5.9 percent of the holes located without an adequate geological or geophysical basis were producers, whereas 18.8 percent of all the holes located on geological and/or geophysical information were producers. In other words, locations based on technical advice were three times as successful as locations made without it.

The effectiveness of scientific exploration and its increased importance in recent years is further evident from a study made by Pratt.[78] In the period between 1931 and 1935 scientific methods were responsible for 80.5 percent of the major oil fields discovered, while only 12.5 percent were discovered through pure random drilling. An examination [79] of the 541 oil fields discovered in the United States from the beginning of 1922 to the end of 1936 shows that the number of major oil fields found through scientific technique far exceeds the number found by random drilling. A division of all reserve discoveries to the end of 1936 indicates that geology was responsible for 37.8 percent, geophysics 16.1 percent, chance drilling 24.5 percent, and the remaining 21.6 percent accounts for oil fields discovered prior to 1922 (figs. 8, 9, and 10). The percentage of random discoveries is large because of East Texas. The chance location of that great field indicates a need for further improvement in finding technique. In the future a mixture of all the sciences—geology, geophysics, stratigraphy, and paleontology—will more than likely be used to discover additional reserves.

Drilling

Advancements enabling the drill to penetrate all kinds of formations at ever increasing depths have been a major factor in extending the life of known reserves. In the middle of 1938 there were in the United States about 125 wells below 10,000 feet.[80] The outstanding change in drilling technique, directly responsible for

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[74] For a fuller discussion of technical advances and exploration see pt. three, sec. II, of this report.

[75] See pp. 137 and 348–349 of this report.

[76] The 1937 ratio was the lowest in nearly 20 years. In 1938 the ratio rose to 22 percent. *Mineral Resources of the United States, 1930*, pt. II, p. 861; *Minerals Yearbook, 1938*, p. 836; *Petroleum Facts and Figures, 1937*, p. 79; James McIntyre, "Completions in 1938 Decline," *Oil and Gas Journal*, January 26, 1939, p. 76.

[77] Drilling outside of known pools which may be regarded as tests of unproved stratigraphic and structural possibilities. Frederic H. Lahee, "Wildcat Drilling," *Oil and Gas Journal*, March 17, 1938, p. 841.

[78] Pratt, *op. cit.*, p. 46.

[79] Kiessling, *et al.*, *op. cit.*, ch. IV.

[80] In April 1938 there were 119 wells drilled below 10,000 feet, Patterson-Ballagh Corporation, *loc. cit.*

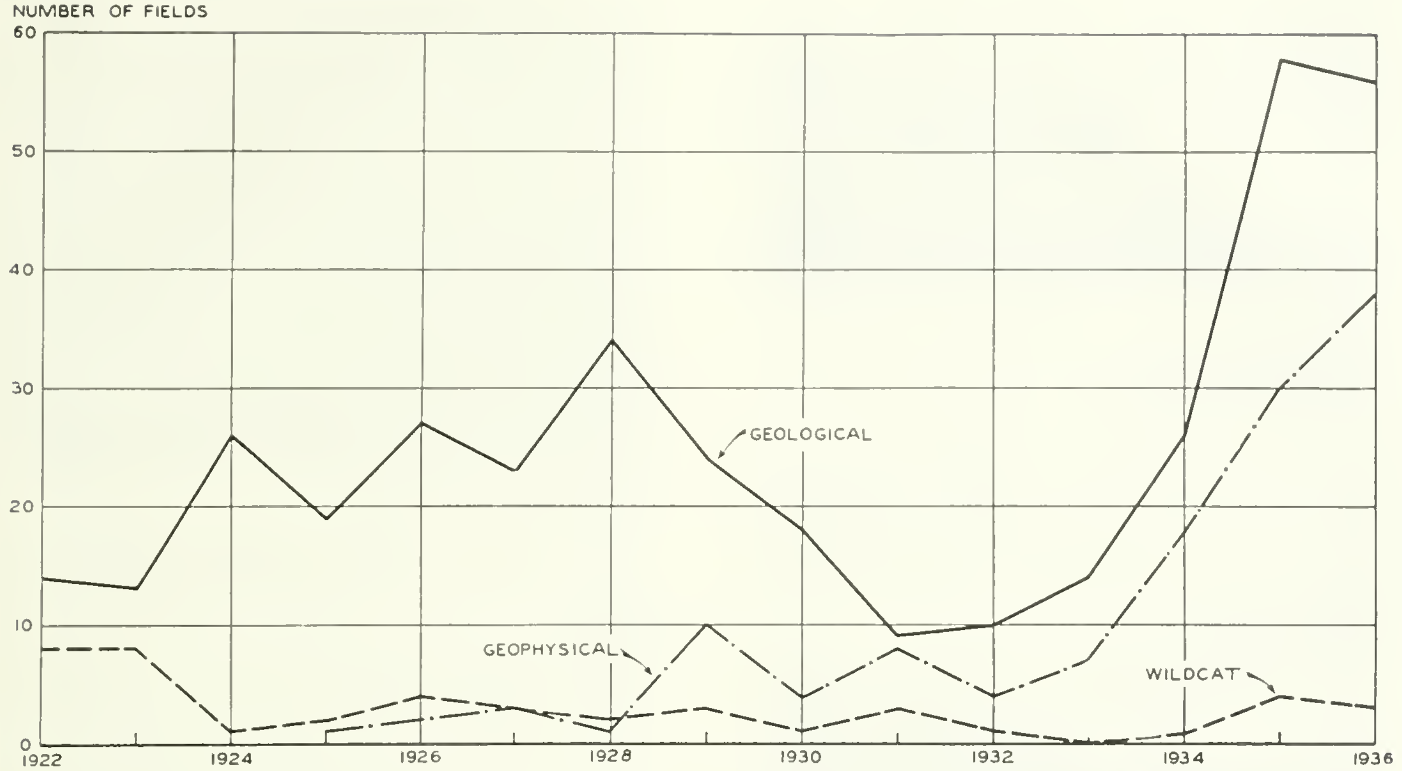

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FIGURE 8.—Number of Million Barrel Oil Fields Discovered by Different Methods of Exploration, 1922–36.

reaching greater depths, was the shift from the cable-tool method[81] to the rotary method. By a long line of improvements[82] the rotary method has reached a high degree of perfection. As a result of development of "hard rock" bits and hard-surface alloys, the rotary system has been adapted for use in practically all formations. The success of the rotary system has been due largely to improvements in circulating muds. Such fluids today are carefully maintained at predetermined standards of weight and viscosity. Important, too, has been the progress made in cement and casing techniques. Cements that will set under abnormal conditions, quick-setting reagents, and new cementing methods[83] have been developed. Seamless steel pipe has supplanted other pipe used for casing.

With increased depths, the trend has been toward larger and heavier rigs, and new improvements have been made in the design of various parts of the equipment so that today are being made machinery and materials which will withstand the stress normally ex-

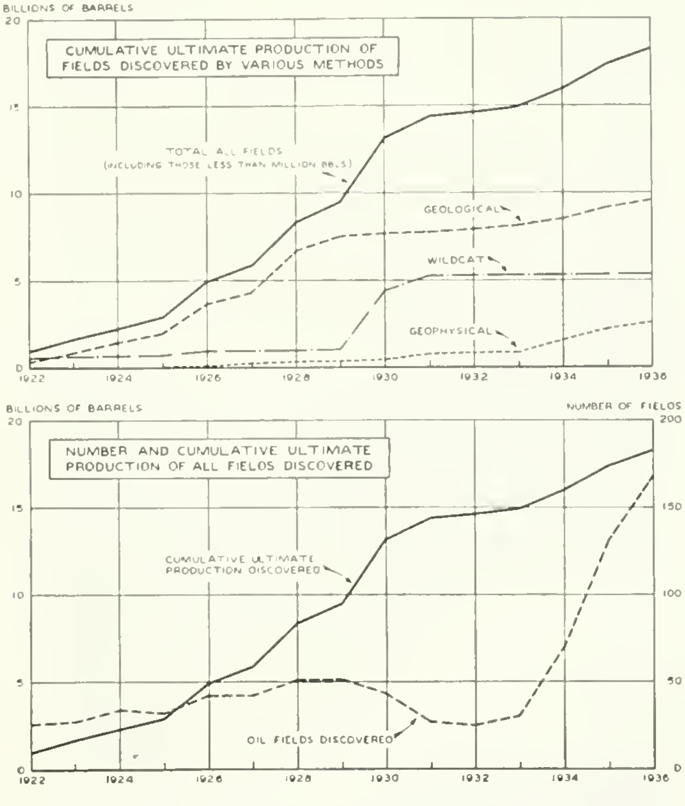

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FIGURE 9.—Contribution to Oil Reserves by Different Methods of Discovery, 1922–36.

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[81] There have been many improvements in the cable-tool method, and the standard cable method in portable outfits is still used for shallow drilling (to about 4,000 feet) and prospecting, since it takes less time to rig up than the modern rotaries. Recent development in portable outfits is discussed by L. G. E. Bignell, "Finding New Pools Facilitated by Use of Portable Machines," *Oil and Gas Journal*, March 17, 1938, pp. 44–45.

[82] For a discussion of technical improvements see pt. three, sec. II, p. 350 of this report.

[83] Such as the multistage cementing method and the "squeeze" method.

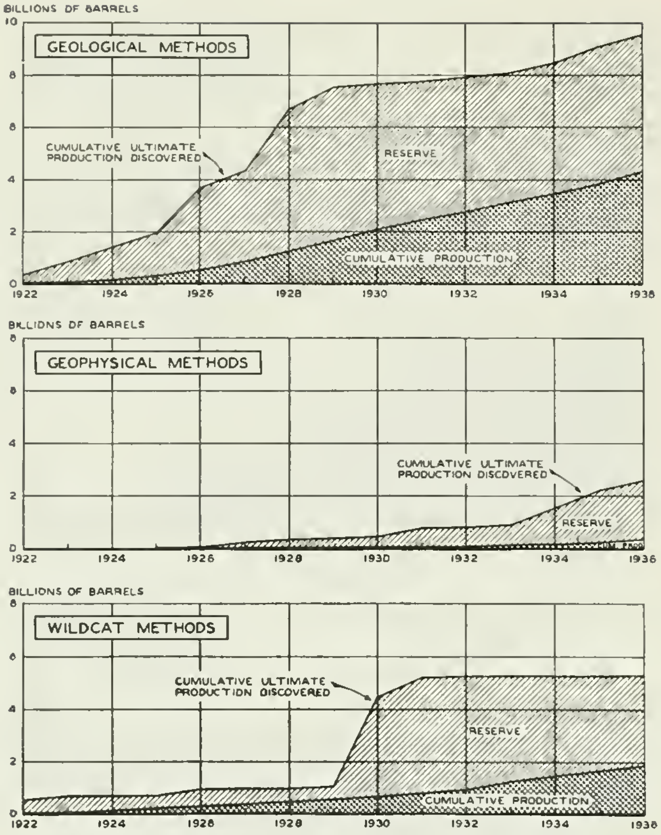

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FIGURE 10.—Cumulative Production and Cumulative Ultimate Production of Million-Barrel Oil Fields Discovered by Different Methods of Exploration, 1922–36.

pected in wells 15 thousand feet deep.[84] Likewise, since power units are heavier and more self-contained, their efficiency has been improved. Although a few electric motors are being used, steam is still the principal source of power for well drilling. Radical changes in oil-field steam plants have resulted in increased power and higher efficiencies.[85]

The development of efficient control equipment permitted drilling in high-pressure areas. Increased pressures and speed in drilling caused crooked holes, but as a result of control and recording devices this tendency has been corrected, and many wells today deviate less than 2° from the vertical.[86] Furthermore, the angle at which a hole is drilled may be so controlled that the bottom of the well will be at a predetermined point many hundreds of feet laterally from the derrick floor.[87] Controlled directional drilling is especially advantageous in off-shore regions or in swampy lands, such as those along the Gulf Coast.[88] At Huntington Beach, Calif., in the period from 1933 to 1937, nearly 30 million barrels of oil were produced from 86 wells [89] slanted from the inlands into the tidal and submerged lands.

Reserves have been extended further because reductions in costs and time have encouraged more drilling. Although the costs have risen with increasing depths, a comparison of earlier costs with recent expenditures for wells of the same depth illustrates technological savings. In the Appalachian field, the average cost between the years 1865 and 1872 for a depth of 1,200 feet was $8,000, whereas in 1928 a 1,200-foot well in this field cost from $3,000 to $5,000.[90] In East Texas in 1931, wells averaging 3,725 feet in depth cost approximately $18,000; [91] while in 1934 one from 3,000 to 3,500 feet cost as low as $8,500.[92]

Tremendous speed has been gained in drilling operations. Recently, a well was drilled in California to a depth of 13,315 feet in 239 days, including 44 days lost because of mechanical trouble,[93] whereas in Texas in 1920, it sometimes took a whole year to reach 3,500 to 5,000 feet. In 1930, it still took between 60 and 90 days to reach a depth of 3,200 to 3,500 feet in Texas, whereas in 1934 only 15 days were required.[94] In fact, in the East Texas field, wells over 3,000 feet are being drilled and completed in 1 week.[95]

Technological advances, then, have facilitated speedier and cheaper drilling to ever greater depths. Maximum recovery from these depths is the next concern of the industry.

Production

Much progress has been made in increasing recovery. Improvements have promoted a more economical method of producing the oil, a higher percentage of recovery, and the pumping of oil from greater depths. Production methods have advanced through increased application of knowledge of conditions that control the occurrence of oil.

The most efficient operation results from maximum use of natural energy. Gas energy [96] has been conserved through better control of gas-oil ratios [97] and by the application of effective methods of back pressure. Encroaching edge water, another source of reservoir energy, has been more effectively utilized in recent years by regulating the rate of flow of wells and by returning any water produced. Remarkable developments in squeezing and other cementing techniques have resulted in reduced gas-oil ratios and successful shutting off of water.[97a] In natural-gas wells, water encroachment and the entrapment of gas are prevented by the application of back pressure at the sand face. Efficient production methods today, therefore, utilize the reservoir energy by maintaining a minimum gas-oil ratio, producing a minimum of water, providing for a slow pressure decline, and avoiding the formation of low-pressure areas.

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[84] K. C. Heald, *loc. cit.* The deepest drilled test at present is 15,004 feet below the earth's surface.

[85] Kiessling, *et al., op. cit.*, ch. V.

[86] H. C. Miller and Ben E. Lindsly, *Petroleum Investigation, 1934*, p. 1154.

[87] Stalcup, *loc. cit.*

[88] Miller and Lindsly, *loc. cit.*

[89] William J. Kemnitzer, "Billion Barrels May Ultimately Be Secured Off Pacific Coast," *Oil and Gas Journal*, November 18, 1937, pp. 39–40.

[90] Arnold and Kemnitzer, *op. cit.*, p. 95.

[91] Harold Vance, "Petroleum in East Texas during 1932," *A. I. M. M. E., Pet. Dev. Tech., 1933*, p. 318; also in *Petroleum Investigation, 1934*, p. 1159.

[92] Statement by Harvey C. Fremming, President, International Oil Workers Union, *Petroleum Investigation, 1934*, pp. 294–295. Other factors to be considered in comparing costs are the changes in the purchasing power of the dollar, the differences among localities in subsurface conditions, and the place utility of the product.

[93] L. P. Stockman, "Drilling Past 13,400 Feet," *Oil and Gas Journal*, February 24, 1938, p. 65.

[94] Fremming, *op. cit.*, p. 294.

[95] Kiessling, *et al., op. cit.*, ch. V.

[96] See also pp. 355–356.

[97] The number of cubic feet of gas produced with a barrel of oil.

The adoption in recent years of methods for maintaining reservoir pressure has increased greatly the ultimate recovery of oil at a lower investment cost per barrel produced. The success of pressure maintenance is shown by Continental Oil Co.'s Tepetate, Louisiana, operations, where the ultimate recovery was increased by at least 40 percent.[98] Cook Ranch field of Shackelford County, Tex., is another instance where pressure maintenance raised the ultimate recovery; in that case from 7,500,000 barrels to 20,000,000 barrels.[99]

Many studies have been conducted to find the most efficient rate of withdrawal, and recoveries have been increased because of adjustment of the rate. Methods for determining the number of wells that should be drilled have been devised.[1] The natural flow may be stimulated, and sometimes abandonment may be prevented by the use of certain completion practices such as treating with acids.

Certain experiments in 1932 with different methods of production proved that increased recovery could be obtained if producing practices were modified to conform with conditions of oil occurrence.[2] In the first case, with the gas well shut in and the oil well producing at a slow rate, the recovery was 51 percent of the oil in the reservoir. In the second experiment, where the gas was conserved but the oil well operated at a rapid rate, the recovery was only 22 percent, and the water showed a tendency to cone toward the well. The third case, in which gas from the free-gas area was produced and wasted, resulted in a recovery of only 11.3 percent.

When the natural energy in the reservoir is exhausted, air or gas lift is employed.[3] The greatest advancement in this technique has been the development of the intermittent and stage-lift devices for low-pressure wells which ordinarily would require excessive volumes of gas.

Production from gas fields causes a rapid decline in formation pressure. Compressors, or mechanical devices comparable to pumps, are used in older fields where the pressure is declining rapidly because no back pressure was earlier applied.

When an oil well will no longer flow naturally or by artificial lift it has to be pumped. Improvements in pumping equipment have been aimed toward lower costs and the ability to produce from greater depths. At the present time pumps are designed for working pressures up to 4,000 pounds, corresponding to depths of 10,000 feet. Oil is now being pumped from 8,600 feet.[4] Probably the most outstanding achievement was the operation of subsurface pumps and the consequent development of hydraulic units. The latter are neither limited by depth nor handicapped by crooked holes. Greatly reducing operating costs is the recent application of multiwell installations, now used for operating a group of wells from a central hydraulic power plant. For production at high rates of speed from large producers the centrifugal pump, introduced about 8 years ago, may be used. In the shallower eastern oil fields economies have been effected by a shift from the walking-beam and steam-engine type to the gas engine or electrically operated band-wheel power and the individual electric pumping jack. In general, fuel requirements have been reduced since multicylinder gas engines and electric drive have been substituted for steam as power for driving pumps.

Progress in secondary recovery methods has meant retrieving from wells once abandoned, oil that might have been lost forever. Where extraction methods were wasteful of natural energy, as much as 90 percent of the oil was left in the ground. At the present time there are two methods practiced on a commercial basis. Water flooding[5] of oil sands has been practiced most widely in the Bradford field in Pennsylvania and New York, since sand conditions are favorable and there are no legal prohibitions. Since 1934 many flooding operations have been undertaken in northeastern Oklahoma and southeastern Kansas.

[97a] C. P. Parsons, "Squeeze Cementing for Controlling Gas-Oil Ratios," *Oil and Gas Journal*, March 17, 1938, p. 103.

[98] The average production per pound of pressure drop has been raised from 3,650 barrels to 42,500 barrels. E. O. Bennett, "Pressure Maintenance," *Oil and Gas Journal*, June 2, 1938, pp. 848–53.

[99] Mitchell Tucker, "New Form of Texas Proration Hinted at Amarillo Sessions," *Oil and Gas Journal*, February 24, 1938, p. 51.

[1] Lyndon L. Foley, "Spacing of Oil Wells"; *A. I. M. M. E., Pet. Dev. Tech., 1938*, pp. 16–22.

[2] Conducted at the annual meeting of the American Petroleum Institute, Houston, 1932; Miller and Lindsly, *op. cit.*, pp. 1220–21.

[3] Compressed air or gas is injected.

[4] "Hydraulic Principles Used by Kobe for Pumping," *Oil and Gas Journal*, February 24, 1938, p. 200.

[5] Water flooding is the introduction of water into special intake wells until the fluid level is high enough to apply sufficient hydrostatic head on the oil sand to cause the water to enter the sand and force its way to surrounding wells where lower pressures prevail. The water follows more porous sands and drives the oil ahead of it to adjacent producing wells. Pump pressures may be applied in addition to hydrostatic pressures. Miller and Lindsly, *op. cit.*, p. 1208.

Water flooding cannot recover all the oil in the ground. Estimates of recovery by this method vary from approximately 15 to 30 percent[6] of the original saturation, leaving approximately 45 to 30 percent of the oil in the ground.

Capable of a much wider application, the other method practiced is the gas or air drive, or pressure drive, usually called repressuring. Air and gas injection methods were successful in some fields where water flooding had failed. H. C. Miller[7] cites an example of gas repressuring near Bradford which increased oil production 25 percent. C. C. Hogg[8] cites another Pennsylvania project repressured continuously since 1924; in 1934 production per month was more than 700 percent greater than prior to gas-drive. In many midcontinent fields, repressuring has been successful. From one oil property in Nowata County, Okla., ultimate recovery of oil has been increased approximately 3,750,000 barrels or 175 percent. A well may flow for some time after the pressure has been restored, thereby cutting the cost of producing.

In connection with a study of repressuring, laboratory experiments conducted by the Bureau of Mines suggested that approximately 52 percent recovery might be expected by normal production methods followed by repressuring, but actual results do not agree with the experiments.[9]

Therefore, even after secondary methods have been applied, there remains in the sands a large proportion of the original amount of oil. Methods have been proposed for draining a greater percentage of the oil than is recoverable by water flooding or gas-air drive. Among these is the proposal for mining oil, especially by the Ranney method.[10]

Oil mining cannot precede the primary methods of production, since working conditions are not safe until the gas and oil pressures have been relieved by prior methods. However, since the total cost of producing oil by flooding ranges from \$1.75 up to \$3 a barrel and the cost by air or gas drive ranges from \$2 to \$4 a barrel,[11] and since recovery by these methods is never beyond 40 percent of the residual oil, the Ranney method of oil mining might compete with existing secondary recovery methods.[12]

Still another process, known as the thermic method,[13] has been experimented with in this country, but without any success. The method was tried in Russia, but the results are not known.

From estimates made by John R. Suman as to oil obtained by different operating methods, we may conclude that present efficient production techniques will recover a higher percentage of oil than could be secured by former primary and stimulative methods together.[14] It is evident that better understanding of fluid relations and underground conditions, coupled with technologic advances in machinery, has resulted in greater production and thereby less cost per barrel, as well as increased ultimate recovery. Furthermore, advanced secondary methods are salvaging oil lost through former inefficient production practices. In the near future new techniques, such as the Ranney process of oil mining, may bring vast reserves of oil and gas within economic limits of recovery.

Transportation and Storage

Advances in the technique of producing oil and gas would have been far less profitable had there been no progress in transportation and storage facilities. Today the largest deposits of oil and gas are far from the great consuming regions. In 1936 almost 600 billion cubic feet of natural gas, or 26 percent of the total production, was transported across State lines, and approximately 42 percent of the total domestic crude moving to refineries in 1937 represented interstate shipments.

Transportation of such volumes is only possible because of continued technological advancements and the rapid extension of pipe lines. In 1937 there were approximately 315 thousand[15] miles of crude, natural gas, gasoline, and natural gasoline pipe lines spread throughout the United States. Of the total percent of the crude receipts at refineries, 71 percent moved in by pipe lines. Furthermore, in recent years many gasoline and natural gasoline lines have been constructed.

Development of gas-transmission systems has meant the utilization of large quantities of gas that otherwise would have been wasted. Natural gas is distributed to cities in most parts of the country from Pittsburgh, Washington, and Buffalo in the East to San Francisco and Los Angeles in the West. In 1920 enormous gas reserves were discovered in certain regions believed at the time to be too far removed from large centers of population to make practical the construction of pipe lines to adequate markets. Substantial improvement in the art of constructing natural gas pipe lines, however, facilitated taking natural gas from Monroe, La., to St. Louis, to Atlanta and Birmingham, Memphis and New Orleans, to Dallas and Fort Worth; and the development of pipe-line systems from the Amarillo field enabled delivery of natural gas to Chicago, Detroit, Minneapolis, and Denver.[16] The average cost of a mile of pipe line is about one-tenth the cost of a mile of railroad line.

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[6] A. John Haworth, "Potential Oil Yields of Reservoir Rocks," *The Science of Petroleum*, vol. I, p. 554; Miller and Lindsly, *op. cit.*, pp. 1224–1225.

[7] *Ibid.*, p. 1197.

[8] *Ibid.*

[9] In three repressuring areas, one in Kansas and two in Texas, ultimate recoveries reached only 37, 37, and 40 percent of the oil in the ground and primary methods recovered only 25, 28, and 20 percent. Haworth, *loc. cit.*

[10] Secondary methods are discussed in greater detail in pt. three, sec. II, of this report, especially pp. 357–358.

[11] George S. Rice, *Mining Petroleum by Underground Methods*, U. S. Bureau of Mines, Bulletin 351, p. 78.

[12] Mining methods recover from 65 to 80 percent of the oil in the ground. Correspondence from Leo Ranney, August 20, 1938

[13] Underground gasification of oil. *Oil and Gas Journal*, March 4, 1937, p. 56.

[14] Quoted by Miller and Lindsly, *op. cit.*, p. 1224.

[15] Walter M. W. Splawn, "Transportation by Pipe Lines," *Oil and Gas Journal*, September 22, 1938, p. 66.

The greatest achievement[17] in pipe lines has been the adoption of oxyacetylene welding and later electric welding. Other improvements have been made in the pipe line itself and in the methods and facilities for trenching and laying the pipe. The routing of pipe lines has been materially aided by aerial photographic mapping.

Oil and gas can be transported for greater distances as a result of better pumps and compressors. The primary change has been a shift from the steam-operated reciprocating type to the centrifugal type, driven either by electricity or by high-speed multicylinder oil or gas engines.

Recent improvements have simplified the problem of maintenance. Murphy points out[18] that, with properly scheduled reconditioning programs and with recently developed applications of welding, the pipe lines now in useful operation in the oil and gas industry in the United States may be kept in continuous operation many years. Underground corrosion has been reduced greatly because of the protection of coating for pipes and cathodic protection. Interruptions in gas-line movements are less frequent since better maintenance programs have been installed in compressor stations. Oil moves through pipe lines today at a maximum speed of about 4 miles per hour.[19] Evaporation and leakage losses in the storage tanks on oil pipe lines have been reduced considerably since vapor-tight tankage has been used.

Also of importance has been the evolution of railroad tank cars and tank trucks.[20] Changes in the construction and design of tanks have promoted safety and reduced the leakage and evaporation losses. Tough, heavy sheet steel has been substituted for iron or wood previously used for tanks. Capacities have been increased, and special tanks have been developed for transporting highly volatile and corrosive products.

Whenever geographically possible, tanker transportation, being the cheapest of all the methods of moving oil, is used. Although in 1937 only 26 percent of the crude receipts at refineries were transported by boat,[21] it is estimated that about 75 percent[22] of the Nation's oil production is transported by water at some stage of its movement from the wells to consumption.

Notable progress in the design and construction of tankers has resulted in increased speed, capacity, and economy of operation. Of major importance has been the introduction of welding in the larger vessels, with a corresponding savings in weight, as well as less opportunity for surface corrosion and less difficulty in cleaning the interior of tanks.

Today, the most efficient steam units developed by American naval engineers consume about 0.65 to 0.7 pounds of fuel per horsepower per hour. The Diesel-powered tankers or motor ships are even more efficient, consuming only 0.35 to 0.4 pounds of fuel per horsepower per hour. The latter are especially suited to long transoceanic voyages and therefore are used less by American than by foreign shippers, because ocean traffic is largely under foreign control.

Closely related to transportation is the problem of storage. It is estimated that in the United States in 1935–37 the motor fuel on hand varied from 36 to 60 days' supply. At the end of 1937, stocks of finished gasoline approximated 70 million barrels.[23] A recent survey by the Bureau of Mines[24] estimated that a minimum working stock of crude oil is about 105 million barrels, aside from needed contingent reserves above ground of about 100 million. This same survey indicated that stocks of crude are stored for a considerable period of time, the weighted average age of all stocks as of June 30, 1936, being about 3 years. About 62 percent of the 311 million barrels of crude stocks had been in storage less than 6 months, but 12.5 percent had been stored more than 11 years.

Important progress has been made in the reduction of losses from seepage, leakage, and evaporation of the lighter constituents. The latter results in the reduction of quality as well as quantity of oil. The chief factor in this reduction has been the shift from all other types of storage to storage in steel shells, which combine qualities of low initial and maintenance costs, movability, low evaporation losses, and reduction of fire hazards. On June 30, 1936, steel tanks comprised 99.5 percent of the total storage capacity. Another contributing factor has been the wider use of floating-type roofs and roofs containing heat-insulating materials, instead of the ordinary steel and wood roofs. Furthermore, tanks today are vapor-tight and equipped with devices to minimize "breathing."

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[16] Ralph E. Davis, "The Natural Gas Supply of the United States," presented before the Mid-West Gas Association, St. Paul, Minn., April 12, 1938; also in *Gas*, May 3, 1938, p. 29.

[17] For complete treatment of the technological progress in the transportation phase, see pt. three, sec. II, p. 360 of this report.

[18] Mike Murphy, "Reconditioning Operations of Pipe Lines are Reviewed," *Oil and Gas Journal*, September 22, 1938, p. 204.

[19] Splawn, *op. cit.* p. 53.

[20] Transportation of crude by railroad and truck is today relatively unimportant. Only 3 percent of the crude receipts in the refinery were transported by tank cars and trucks, *Minerals Yearbook, 1938*, p. 845. Railroad transportation of crude has been declining according to the results of a study by the Interstate Commerce Commission, in which railroad tonnage in 1936 was compared with a base figure representing the average tonnage in the period between 1923 and 1925. While interstate movement of crude was mounting rapidly, the tonnage carried by railroads in 1936 had decreased 62.9 percent, Splawn, *op. cit.*, p. 66.

[21] *Minerals Yearbook, 1938*, p. 845.

[22] H. Stanley Norman, "Ocean Tankers, Inland Barges, Supplement Pipe Lines," *Oil and Gas Journal*, September 22, 1938, pp. 60–61.

[23] *Minerals Yearbook, 1938*, pp. 874, 875.

[24] U. S. Bureau of Mines, R. I. 3417, *Survey of Crude Oil in Storage, 1936–1937*, pp. 33–34.

In 1921, before vapor-tight tanks and other evaporation reducing methods were adopted, the average yearly evaporation loss [25] from the well to the refineries was 6.2 percent of gross production. Recent observations [26] indicate an average reduction of about 68 percent in this loss, despite the fact that the average volatility of the crude oil handled has increased within the past few years.

Modern storage facilities better conserve the lighter fractions of the crude. One analysis [27] shows that the distillates recoverable from oil in storage before 1925 compare unfavorably with those from the oil stored in later periods, in spite of the fact that the former was from flush production and originally contained a greater quantity of lighter fractions. The oil stored from 1931 to 1935, however, compares favorably with that stored in 1936. In part, the favorable showing of the oils stored from 1925 to 1935 reflects the improvement in equipment and the adoption of practices for preventing losses from evaporation.

Between 1924 and 1934 evaporation losses in the refinery had been reduced from 2.1 percent of the crude run to stills to approximately 1.5 percent, even though the average gasoline marketed in recent years is more volatile than that sold in 1924.[28]

Special spheroid-shaped tanks have been designed for storing highly volatile products such as casing-head gasoline or volatile crude oil. For the storage of municipal gas special spherical tanks have been constructed.[29]

From the story presented, it may be seen that technology has kept pace with the increasing demands and needs of the petroleum industry and that great savings have been effected in the production phase. Savings in the use of the crude will be discussed next.

Refining

Technological advancements in refining have met the problem of evolving processes which will yield maximum amounts of the major product, and refining equipment which permits flexible operations, and at the same time keeps the cost at a minimum, has been developed.

The refining process is primarily a separation of individual crude oil fractions by the basic processes of distillation, fractionation, and condensation, supplemented by more recent processes, such as cracking, etc. Continuous progress has been shown in the development of the distillation technique, and present-day operations include many improvements made before the introduction of cracking.

The growth of continuous operation, the substitution of pipe stills for the horizontal shell stills, plus the development of the bubble tower and other devices permitting closer fractionation, have been important improvements, but the revolutionary change came through the introduction of thermal cracking,[30] a process obtaining a greater yield of gasoline from the crude. Since about 1912, when commercial cracking operations first began, the amount of crude cracked has continued to increase; and in 1936 the amount of cracked gasoline exceeded that of straight-run gasoline for the first time.[31] A new cracking process, developed within the last few years, eliminates heavy fuel oil residuum and from any type of crude or refinery residuum, produces high-grade gasolines.[32]

Of increasing importance is the recent process, polymerization, by which high octane gasoline can be made from either natural gas or refinery gases that were formerly wasted or used directly for fuel. Statistics on polymerization are not yet available, but it has been estimated that over 9 billion gallons of polymer gasoline may be produced yearly in the United States from hydrocarbon gases, of which over 1 billion gallons may be blending stock of 95 to 100 octane rating.[33] Furthermore, through the development of catalytic polymerization,[34] it is possible to use petroleum as a raw material for the production of chemical derivatives.[35]

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[25] An estimate of the total evaporation loss of crude petroleum in the midcontinent area prepared by J. H. Wiggins, U. S. Bureau of Mines, *Bulletin 200*, 1921, and *Technical Paper 319*, 1923; also *Petroleum Investigation, 1934*, p. 1946.

[26] Testimony by Ludwig Schmidt, U. S. Bureau of Mines, *ibid.*, p. 1947; also Ludwig Schmidt, *Applied Methods and Equipment for Reducing Evaporation Losses of Petroleum and Gasoline*, Bulletin 379, U. S. Bureau of Mines, 1934.

[27] U. S. Bureau of Mines, R. I. 3417, *op. cit.*, pp. 15–25.

[28] Schmidt, *op. cit.*, pp. 1950–54.

[29] Wilbur F. Cloud, *Petroleum Production*, University of Oklahoma Press, 1937, p. 566.

[30] A detailed description of the technical progress in refining is included in pt. three, sec. II, pp. 363–368, of this report.

[31] *Minerals Yearbook, 1937*, p. 1024. Cracking operations may increase still further as a result of the reduction, effective October 1, 1938, in Dubbscracking royalty costs. In 1919 the rate was 15 cents a barrel; it was cut to 10 cents in 1934, and at the present time is 5 cents per barrel throughput. "Refinery Expansion," *Oil and Gas Journal*, August 25, 1938, p. 45.

[32] The Houdry catalytic cracking process yields upwards of 80 percent gasoline from low-grade crudes and refinery residuum. The yield consists entirely of gas, gasoline, and gas oils. The octane number of gasoline produced ranges from 77 to 81. Eugene Houdry, Wilbur F. Burt, A. E. Pew, and W. A. Peters, Jr., "The Houdry Process," *Oil and Gas Journal*, November 24, 1938, pp. 40–45; also "Houdry Process," *Fortune*, February 1939, p. 56.

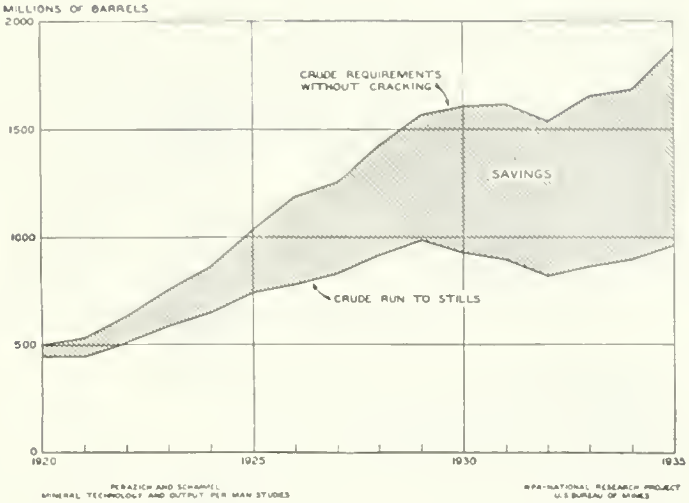
[33] G. Egloff, J. C. Morrell, and Edward F. Nelson, "Motor Fuels from Polymerization," *Oil and Gas Journal*, November 12, 1937, p. 176.

In conjunction with cracking and polymerization, the hydrogenation process[36] converts crude oil completely into motor fuel. Although a few hydrogenation plants are operated for special products, present economic conditions prevent a wide commercial adoption of this process. It is possible also to produce synthetic hydrocarbon products by applying the hydrogenation process to coal, but in the United States this idea is still in the experimental stage.

Refineries readily raised the quality of gasoline when high-compression engines in automobiles and airplanes created a demand for gasoline which did not knock. Important in this respect has been the discovery that the octane number[37] can be improved by the addition of minute quantities of tetraethyl lead, and today 75 percent of the gasoline sold contains this antiknock agent. There is a limit, however, to the amount of lead that can be added; in addition to cracking or reforming straight-run gasoline, requirements for airplane motor fuels have been met by blending exceedingly high-octane gasoline with low-octane gasoline.

For extracting gasoline from natural gas, better methods which conserve oil used in former processes have been developed.[38] Although natural gasoline primarily is used for blending, it is limited as to quantity, and refiners have resorted to polymerization coupled with hydrogenation to furnish high-octane blending stocks.

As a result of all these processes, refiners have been able in 10 years to raise the average octane number of regular brand gasoline from approximately 51 in 1928 to the present average of 71.[39] Gasolines up to 100 octane are now being commercially produced.[40] Furthermore, there has been a decided rise in the yields of gasoline and corresponding savings in the crude runs to stills (fig. 11). The average yield of gasoline in 1899, when there was relatively no demand for the product, was approximately 12.9 percent.[41] With the introduction of the cracking process and with increased demands for gasoline after the war, it rose to 26 percent in 1920.[42] Since that time, due to rapid advances in cracking technique, the average yield has been raised to 44 percent.[43] Axtell J. Byles, president of the American Petroleum Institute, in commenting on the development of the cracking process and its effect on conservation,[44] estimated that without cracking more than 1 billion barrels of additional petroleum would have been needed to satisfy the 1937 demand for products. At another time,[45] Byles calculated that by the cracking process alone over 6½ billion barrels of crude oil had been saved in the past 15 years, or an amount equivalent to three-fourths of the preceding 10 years' crude production. It has been estimated that the quantity of gasoline[46] that can be made by the polymerization process from noncondensible gases would equal from 10 to 25 percent of the total consumption in the United States. The American Petroleum Institute[47] estimates that gasoline yield from crude will continue to rise in the future, so that by 1960, crude oil requirements will actually decrease while motor-fuel demand increases. It is technically possible at present, although not economically feasible, to effect a higher yield than that predicted for 1960.



PERAZICH AND SCHIMMEL
MINERAL TECHNOLOGY AND OUTPUT PER MAN STUDIES

WPA-NATIONAL RESEARCH PROJECT
U.S. BUREAU OF MINES

FIGURE 11.—Crude Petroleum Conserved by Use of the Cracking Process.

For ordinary automotive lubricants, the quantity of crude suitable has been increased greatly with the introduction in the last 10 years of solvent refining processes. Progress has been made also in methods for

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[34] Converting of olefin hydrocarbons which were produced by cracking butane and pentane.

[35] See Egloff, Morrell, and Nelson, *loc. cit.*, and Carlton Ellis, "Trend in Petroleum Derivatives," *Oil and Gas Journal*, April 14, 1938, p. 59.

[36] A process by means of which heavy hydrocarbons are decomposed by heat and pressure in the presence of free hydrogen and catalysts.

[37] A standard of measurement of the ability of fuels to resist detonation.

[38] Another conservation measure is the utilization as bottled or liquefied gas of a large part of the volatile fractions of natural gasoline, formerly lost by weathering.

[39] W. W. Schumann, "Automatic Engine Design Governs Modern Refinery Methods," *Oil and Gas Journal*, November 3, 1938, p. 43.

[40] Egloff, Nelson, Morrell, *Cracking Oils the World Over*, p. 5.

[41] *A. I. M. M. E., Pet. Dev. Tech., 1938*, p. 291, 20 n.

[42] Pogue, *op. cit.*, pp. 27–29.

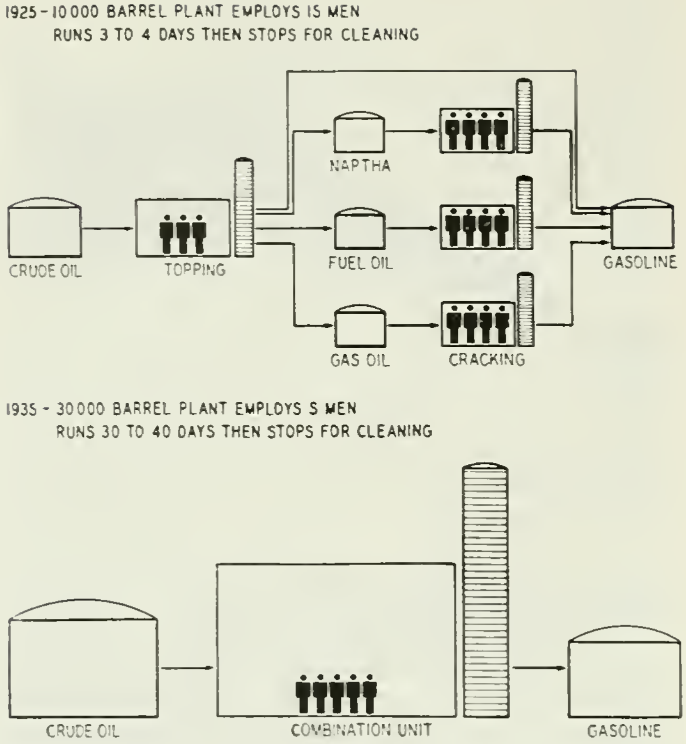
[43] *Minerals Yearbook, 1938*, p. 868. Since 1931 the yield has remained about the same. *Petroleum Facts and Figures, 1937*, p. 117.

[44] Axtell J. Byles, "But One Correction Indicated, Byles Warns North Texas," *Oil and Gas Journal*, March 3, 1938, p. 32.

[45] Byles, "The Oil Outlook," *The Mines Magazine*, official organ of the Colorado School of Mines Alumni Association, special petroleum number, February 1936, p. 13.

[46] M. B. Cooke, H. R. Swanson, C. R. Wagner, "The Thermal Polymerization Process Used by Pure Oil on Olefin-Bearing Gases," *Oil and Gas Journal*, November 14, 1935, pp. 57–64.

[47] *A. I. M. M. E., Pet. Dev. Tech., 1937*, pp. 255–256.


1925 - 10 000 BARREL PLANT EMPLOYS 15 MEN
RUNS 3 TO 4 DAYS THEN STOPS FOR CLEANING
CRUDE OIL
TOPPING
NAPTHA
FUEL OIL
GAS OIL
CRACKING
GASOLINE
1935 - 30 000 BARREL PLANT EMPLOYS 5 MEN
RUNS 30 TO 40 DAYS THEN STOPS FOR CLEANING
CRUDE OIL
COMBINATION UNIT
GASOLINE

Perazich and Schimmel Mineral Technology and Output Per Man Studies
U. S. Bureau of Mines W. P. A.—National Research Project

FIGURE 12.—Effect of Increasing Capacity and Continuous Process on Labor Requirements in Petroleum Refining.

treating lubricating oils and the lighter distillates, especially cracked gasoline.

Through greater use of heat exchangers, wider adoption of ordinary control devices, and other improvements in refining equipment, there has been a decided drop in amount of fuel used in refineries. During the 11 years, 1926–36, the energy consumed in refining a barrel of crude petroleum decreased from 847,900 B. t. u. to 643,400 B. t. u.,[48] a drop of 24 percent. These economies are more striking when it is realized that the increase in the variety and volume of products produced tends to offset advances in plant economies. Furthermore, in recent years, refiners are using as fuel, refinery gases and other fuel byproducts formerly allowed to go to waste. The cost of operation has been reduced further by improved methods for combatting corrosion. The increased size of refineries and the recent trend toward combination plants also have reduced waste and cost of operation.

From this very brief survey [49] of refining accomplishment it may be concluded that the refiner has been conserving all the refinery fractions possible and keeping costs low. No doubt he will go on improving products now in demand, developing new products, and producing greater portions of the more urgently demanded products.

Net Gains in Productive Efficiency

On the whole, it may be said that advances in technology have more than overcome the increasing difficulties in winning the oil and getting it ready for use. Increased costs of exploratory drilling have been offset by greater certainty in the search. In the production branch of the industry in the last 50 years the output per man has increased more than 500 percent, an increase all the more striking when considered in the light of increasing difficulties due to greater depths and differences in new production areas.[50] There is also an upward trend in refinery output per man (fig. 12). Productivity was measured by input of crude oil without allowance for changes in products. Moreover, in transportation, productivity of labor also has risen sharply. For instance, from 1920 to 1930 the volume transported by pipe lines was more than doubled, whereas the working force was cut by approximately one-third. Between 1929 and 1935 the barrels transported per man per day increased over 80 percent.

Another way of measuring the net results of the struggle between technology and increasing difficulties is to consider the trend of prices over a long period of time. Although price is affected by many factors other than technological progress, it appears that the downward trend in price reflects reduced costs of production. A recent study by Pogue [51] of the average retail prices of gasoline, excluding sales tax, in 50 representative cities, indicated that the price declined from 21.06 cents per gallon in 1923 to 14.58 cents per gallon in 1937. In order to compare the price of gasoline with other commodities, Pogue, using 1926 as a base year, calculated a retail price index which he compares with the Bureau of Labor Statistics Price Index of 784 commodities at wholesale. In 1937 the retail price of gasoline averaged 69.5 percent of the 1926 level, whereas the commodity index stood at 86.3 percent. Pogue measured the decline in prices still another way: he calculated that a parcel of the 784 commodities would have exchanged for 24.2 percent more gasoline in 1937 than in 1926. The price of crude, also, has decreased, absolutely as well as relative to prices of other commodities.[52]

For natural gas, values at the wells are better indications of technical progress, since they do not reflect costs of transportation. From 1922, the first year in which such figures are available, to 1937, the average value decreased from 11.1 cents to 5.3 cents. Since 1922, the average value at points of consumption also has gone down, but only slightly.[53]

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[48] Works Progress Administration and U. S. Bureau of Mines, *Fuel Efficiency in Cement Manufacture, 1909–1935*, 1938, pp. 7–9.

[49] See pt. three, sec. II, p. 367, of this report.

[50] Kiessling, *et al.*, *op. cit.*, ch. II.

[51] Joseph E. Pogue, "Gasoline and the Consumer," *Oil and Gas Journal*, September 22, 1938, p. 88.

[52] See Kiessling, *et al.*, *op. cit.*, ch. VI.

The foregoing facts are summarized well by Pogue, who states that consumers "were enabled to purchase gasoline in ever-increasing volume through good times and bad; the quality of the gasoline they bought steadily improved; and the prices they were required to pay carry the suggestion that there must have been a background of great technological progress in the oil industry, the fruits of which were transmitted to the consumer."

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[53] *Mineral Resources of the United States, 1924*, pt. II, p. 323, *Minerals Yearbook, 1937*, p. 1062; *Minerals Yearbook, 1938*, p. 909

CHAPTER 4.—TRENDS IN THE USE OF OIL AND GAS

Growth of Consumption

In the last four decades the standards of living of the American people probably have risen more rapidly than in any other comparable period in the history of our country. To a considerable extent this is a result of the development of automotive transportation. The spectacular growth of the consumption of motor fuels and oils has been accompanied by wastes in the production and refining of petroleum, some of which, as we shall see, arose from conditions under which oil was produced and some of which more or less inevitably resulted from the rapid expansion of the industry. It is the purpose of this chapter to trace the growth of the demand for oil and gas, particularly for individual products, and also to indicate inefficiencies which have arisen in connection with the consumption of petroleum products and the extent to which they are being eliminated.

In 1909 the consumption of crude petroleum in the United States amounted to 167.1 million barrels. Four years later the figure had risen to 261.7 million barrels.[1] Although adjustments for production of benzol and natural gasoline, for exports and imports of refined products, and for changes in stocks cannot be made, these figures indicate roughly the growth in the domestic demand for all oils. Since, during this prewar period, exports of refined products far exceeded imports, the domestic demand for all oils was somewhat less than the domestic consumption of crude petroleum.

In 1918 the domestic demand for all oils amounted to 359.4 million barrels.[2] The domestic demand rose steadily until 1929, when it reached 940.1 million barrels (fig. 13). During the ensuing depression the demand fell and in 1932 amounted to 835.5 million barrels. This decline was by no means as drastic as that which characterized many branches of the industrial economy. With business recovery the demand for petroleum products again rose, and in 1937 the indicated domestic demand for all oils amounted to 1,168.4 million barrels, the all-time peak.

Although the growth of consumption of petroleum products has slowed down somewhat since 1929, the indicated demand in 1937 exceeded that in 1929 by far more than the relative gain in population.[3] Therefore the per capita consumption of all oils has continued to rise. In 1913 the consumption amounted to approxi-

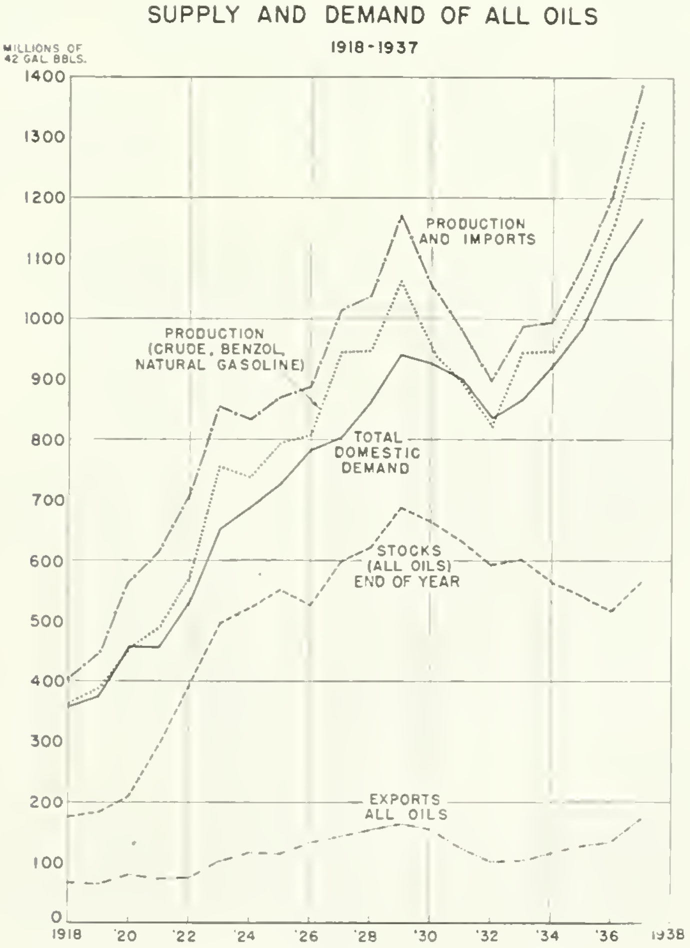

FIGURE 13.

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[1] United States Bureau of Mines, *Mineral Resources of the United States, 1921*, pt. II, p. 291.

[2] This figure includes domestic production of natural gasoline and benzol as well as crude petroleum and also allows for imports, exports, and changes in stocks of refined products as well as crude petroleum. *Mineral Resources of the United States, 1929*, pt. II, p. 425.

[3] The average rate of growth in the domestic demand for all oils between 1929 and 1937 amounted to 2.73 percent per year, whereas the rate of growth of population approximated only 0.78 percent per year.

mately 2.5 barrels per capita. In 1929 the figure was 7.7 barrels per capita, and in 1937 it had risen to 9.0 barrels per capita. The great increase in per capita consumption of petroleum products has resulted in large part from the increase in the use of motor vehicles. In 1913 there was 1 car for every 77 persons, whereas in 1929 the ratio was 4.6 persons per car and, in 1938, 4.4 persons per car.

In only 2 years since 1917 has the domestic demand for petroleum products exceeded the supply of oils available from domestic production of crude, natural gasoline, and benzol.[4] In 1931 and 1932 the demand for oils was less than production by 19,000 barrels and 36,000 barrels, respectively, or by only 0.7 percent and 1.6 percent. Moreover, domestic consumers always have had available sizable stocks of oils which could be drawn on. Until the end of 1929 actual decreases in stocks occurred only in 2 years, 1918 and 1926. Yet in every subsequent year, except in 1933 and 1937, there were decreases in stocks, but withdrawals never would have been necessitated except for exports.[5] The heavy imports of crude oil, 1920–22 (approximating one-quarter of the domestic production), as well as large imports of refined products, 1929–32 (in no year more than 5 percent of the domestic demand), made possible exports, sales of bunker oil in foreign trade, and increases in the stocks of oils on hand.

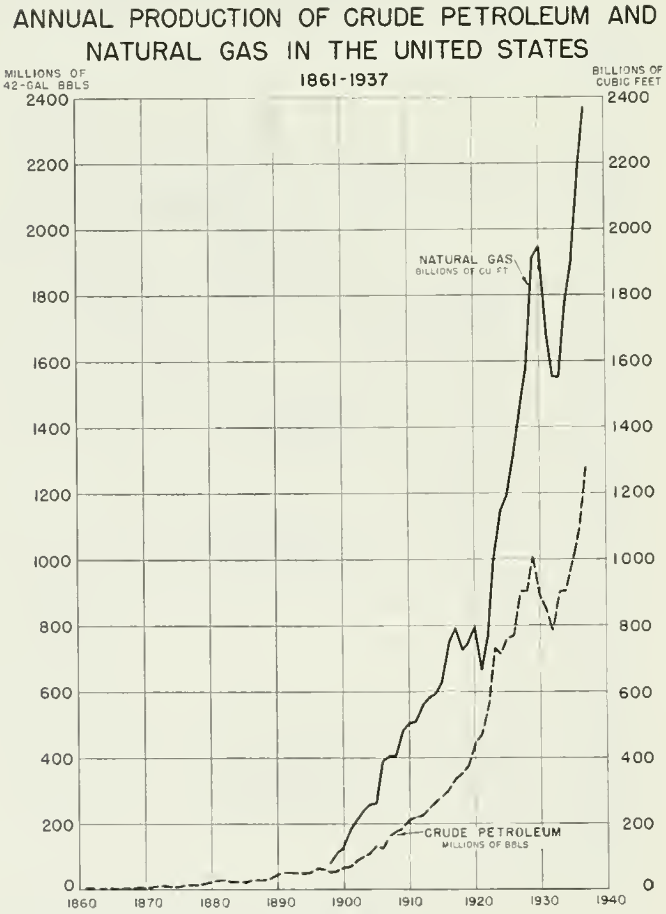

FIGURE 14.

As we have already noted, the oil industry has supplied the rapidly rising demand for petroleum products with increasing efficiency and at declining prices. In part the decline in prices has been due to excess production and to the upward trend in stocks, but mainly it has been a reflection of the greater economy in the producing and refining of crude petroleum.

Natural-gas consumption in the United States amounted to somewhat less than 100 billion cubic feet in 1898. Consumption grew almost continuously until 1917, when it amounted to 795 billion cubic feet.[6] In the next year there was a drop, but by 1920 the figure for the industry again approximated 800 billion cubic feet (fig. 14). After 1921 the market for natural gas rose regularly to a 1930 peak of 1,943 billion cubic feet. After the subsequent depression consumption rose to an all-time high of 2,448 billion cubic feet in 1937.[7] The relative gain since 1933 is far greater for natural gas than for crude petroleum.

The average value of natural gas at points of consumption reached a peak of 29.1 cents per thousand cubic feet in 1922. Since that year the average cost to consumers has tended to decrease, although from 1926 to 1937 there existed a slight down movement.[8] On the other hand, the average value of natural gas at wells has dropped considerably since 1922, the first year for which such data are available.[9] The average value dropped from 11.1 cents in 1922, to 5.3 cents in 1937. The widening spread between values at wells and at points of consumption reflects in part the greater transportation expenses. Recent discoveries of major gas fields have been in the Southwest, so that over the last 20 years the distance between wells and points of consumption has been extended considerably.

Geographical Distribution of Consumption and the Problem of Transportation

Crude Oil

As indicated in chapter 3, the production of crude oil is highly concentrated in the midcontinent field, in the

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[4] See annual issues of the *Minerals Yearbook*. If bunker oil for foreign trade be excluded from the domestic demand (as is done in some of the tabulations of the Bureau of Mines) then the domestic demand probably never has exceeded the domestic production of all oils, at least not since 1917.

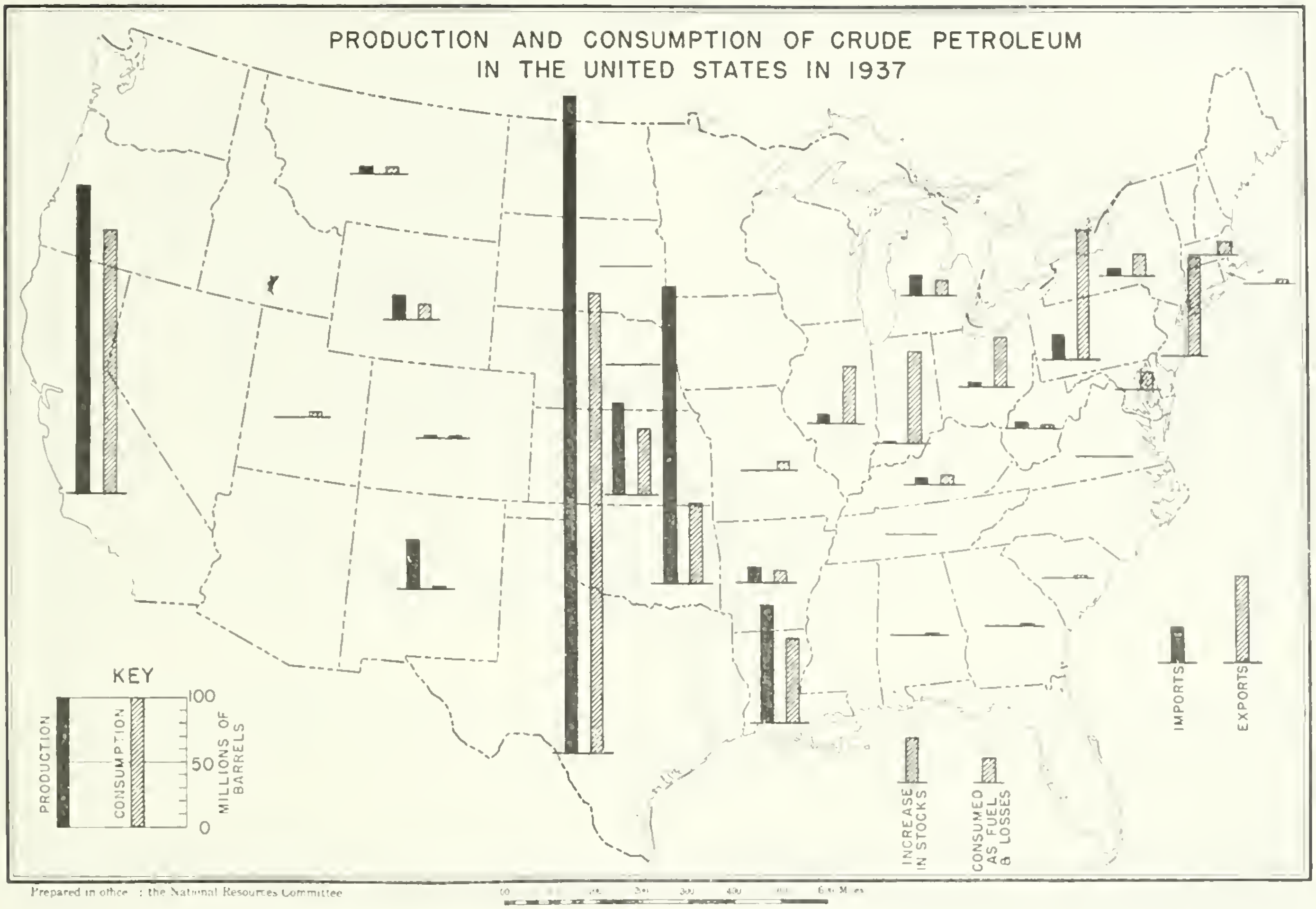
[5] Although for some States it is usually more economical to export crude or refined products than to ship to other States.

[6] *Mineral Resources of the United States, 1921,* II, pp. 340–41.

[7] U. S. Bureau of Mines. *Natural Gas Consumption Sets New Record in 1937,* Mineral Market Reports, No. M. M. S. 682, December 13, 1938, p. 1.

[8] *Minerals Yearbook, 1937,* p. 1062.

[9] *Ibid.; Mineral Resources of the United States, 1924,* pt. II, p. 323.


PRODUCTION AND CONSUMPTION OF CRUDE PETROLEUM
IN THE UNITED STATES IN 1937
KEY
PRODUCTION
CONSUMPTION
100
50
0
MILLIONS OF BARRELS
IMPORTS
EXPORTS
INCREASE IN STOCKS
CONSUMED AS FUEL & LOSSES
0
600 Miles

Prepared in office of the National Resources Committee

Figure 15.

Gulf coast district, and in California (fig. 15).[10] Indeed, in 1937 these three territories contributed 93 percent of the national output. The same sections accounted for a much smaller percentage of the consumption of crude oil—in 1937 approximately 61 percent of the runs of crude oil to refineries.[11] Thus, approximately one-third of the production of crude oil in these sections was transferred to other districts, and even within these territories there were, of course, extended movements of crude from producing areas to refineries.

The ranking oil States, Texas and California, lead in refining activity (fig. 15). Otherwise there is little relationship between rank in production and rank in consumption of crude. The pattern of refining is more closely related to the distribution of population and, consequently, to the consumption of gasoline than is the production of crude oil. Thus Pennsylvania, New Jersey, and Indiana are more important refining centers than are the oil-producing States, Louisiana and Texas. In Oklahoma and Texas, production of crude oil exceeded consumption by 319 million barrels in 1937, or approximately 70 percent of the total excess output in producing States. Owing to the greater development of refining in Texas, the excess production in that State was somewhat less than that in Oklahoma. Almost all the remaining excess output was accounted for by New Mexico, California, Louisiana, and Kansas. These differences in production and consumption have been determined without adjustments for exports or imports of crude oil or without allowances for changes in the stocks of crude at refineries.

Although the movement of crude to refineries is made up of shipments in nearly all directions from producing fields, there are three major types of shipments. The movement of crude to foreign countries is largely composed of shipments from California and Texas.[12] The

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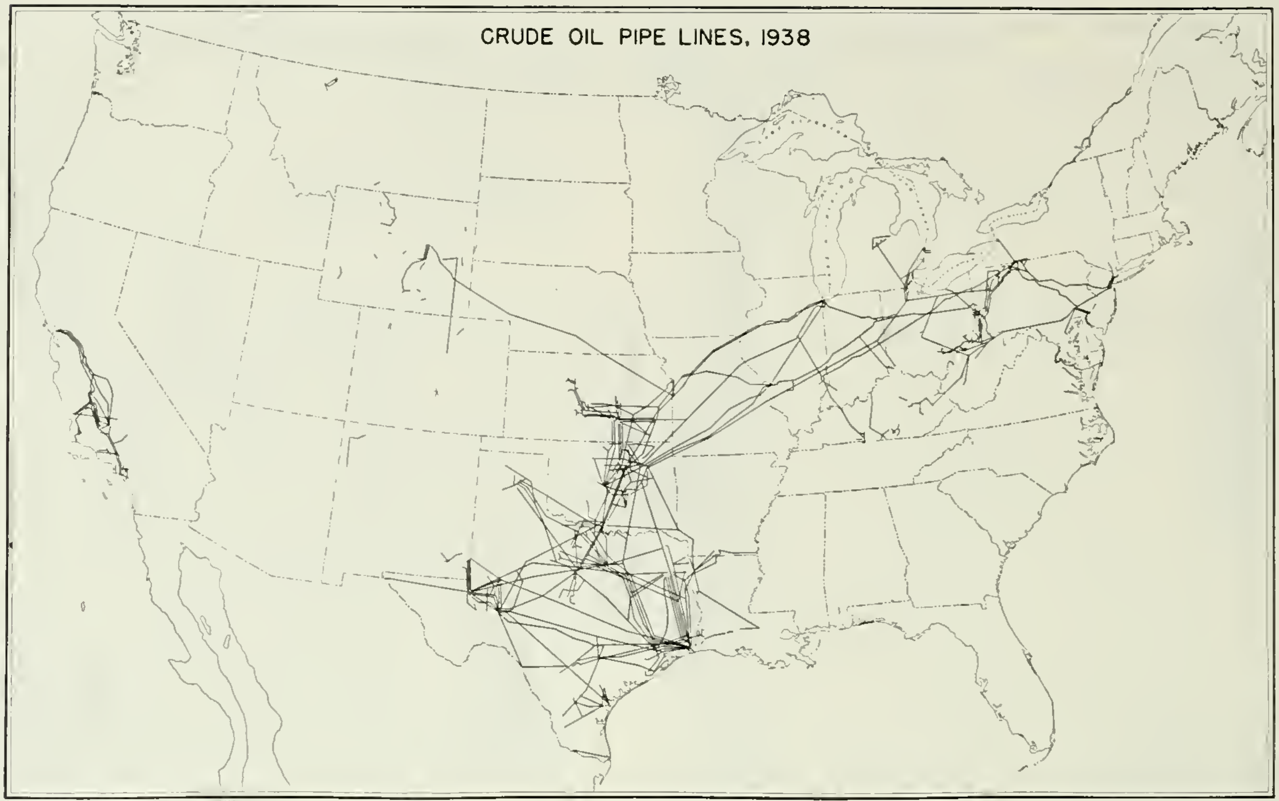
[10] See pt. two, sec. I, ch. 2, fig. 4, of this report.

[11] *Minerals Yearbook, 1938*, pp. 843–844.

[12] In 1937, of 67 million barrels of exports, 23 million barrels moved from California mainly to Japan and the Far East and to the west coast of Canada; 30 million barrels moved from Texas, mainly to Europe and Canada; 3 million barrels, from Louisiana to approximately the same market; and 9 million barrels of crude were exported from Oklahoma, mainly by pipe line to Canada. *Minerals Yearbook, 1938*, pp. 848–849, 899; also see *Oil and Gas Journal*, March 25, 1937, map opposite p. 112.



PREPARED IN OFFICE OF THE NATIONAL RESOURCES COMMITTEE

FIGURE 16.

most important domestic movement of crude oil is by tanker from the Gulf coast sections of Texas and Louisiana to refineries along the seaboard north of Virginia. This east coast district, which excludes the oil-producing sections in the western parts of Pennsylvania and New York, consumed approximately 198 million barrels of crude petroleum in 1937, 24 million of which were imported. Of the remainder, only about 7 million barrels came from States other than Texas, Louisiana, Oklahoma, and New Mexico.[13] Moreover, the east coast district receives the major part of the crude oil imported into the country.

The third major movement of crude oil is by pipe line from midcontinent fields in Kansas, Oklahoma, and north Texas to refining centers in midwest territory between the upper Mississippi River and the Allegheny Mountains. Most of the crude which moved in 1937 to western Pennsylvania and Ohio came from Oklahoma. Refineries in Indiana and Illinois obtained their supplies principally from Oklahoma and Kansas. There are some producing fields in Texas and Oklahoma which send crude oil either to the north for midwestern refineries and for exports to Canada or to the south for tanker shipment to the east coast and to European markets. Approximately 42 percent of the total movement of domestic crude oil represents interstate shipment. This portion has remained constant in the last 3 years.[14] Of pipe-line movements approximately 45 percent were interstate.

Current data on the use of different media of transportation for crude petroleum indicate that in 1937 approximately 71 percent of the crude oil was moved by pipe lines, about 26 percent by waterway carriers, and about 3 percent by tank car and truck.[15] Although the main movement is still by pipe line, within the last decade transportation by tanker has increased relatively.

Gasoline

The consumption of gasoline is distributed among States much more widely than the production of gasoline (fig. 17). Petroleum refineries are located mainly in oil-producing States, at Atlantic coast ports reached by low-cost water transportation, and on the Great Lakes. These three districts produce gasoline for export and also for shipment to other parts of the country. The east coast district produces large quantities of gasoline, but it still must obtain further supplies from the Southwest. Other areas with a deficit of local supply are the Southeast and the upper Mississippi Valley.

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[13] The New Mexico shipments to the east coast amounted to only 9 million barrels and moved by way of the Texas Gulf coast and then by tanker. The 12.5 million barrels obtained from Oklahoma also moved through Texas and then by tanker

[14] U. S. Bureau of Mines, *Minerals Yearbook, 1938*, pp. 845–846.

[15] *Ibid.* In 1932 almost the identical percentages were reported by the Federal Coordinator of Transportation, although the total estimated movement increased from 711 million barrels in 1932 to 1,190 million barrels in 1937; Federal Coordinator of Transportation, *Freight Traffic Report*, Vol. 2, p. 53. According to the Interstate Commerce Commission, approximately 4.1 million tons of crude petroleum in 1937 originated as revenue freight on class I railroads. This tonnage was equivalent to approximately 26.6 million barrels, or about 2.1 percent of the total domestic production of oil for 1937.

The major exports of gasoline are from the Gulf coast area and California. In 1937, Texas and Louisiana exported approximately 20 million barrels of gasoline and California nearly 14 million barrels. Of domestic movements of gasoline, by far the most important is that by boat from the Gulf coast to the Atlantic coast, amounting in 1937 to 104 million barrels.[16] The deficit in gasoline production in that year amounted to about 29 million barrels in New England and to about 64 millions in the 12 States east of the Mississippi and north of the Ohio, plus the District of Columbia. Somewhat more than 10 million barrels of gasoline appear to have moved from the Gulf coast district to New York. Thus, in addition to supplying most of the crude requirements of the east coast, Texas and Louisiana shipped enough gasoline to that section to satisfy the additional demands for motor fuel. Refining centers in Pennsylvania and New Jersey produced approximately 23 million barrels of gasoline in excess of local consumption in 1937. This quantity appears to have been consumed primarily in New York State.

From the refining district in northwestern Indiana, gasoline is shipped to the other States bordering on Lake Michigan. In 1937 Indiana had an excess production of approximately 28 million barrels of gasoline, most of which appears to have been shipped to Michigan, Illinois, and Wisconsin. Oklahoma and Kansas in 1937 produced approximately 49 million barrels of gasoline in excess of local consumption. In the main, this volume of motor fuel was transported to the upper Mississippi Valley States of Minnesota, Wisconsin, Iowa, Nebraska, and Missouri. A large part of this movement is made by pipe line. The only other important domestic movement of gasoline is that from refineries in California to consuming centers in Oregon, Washington, and intermountain States.[17]

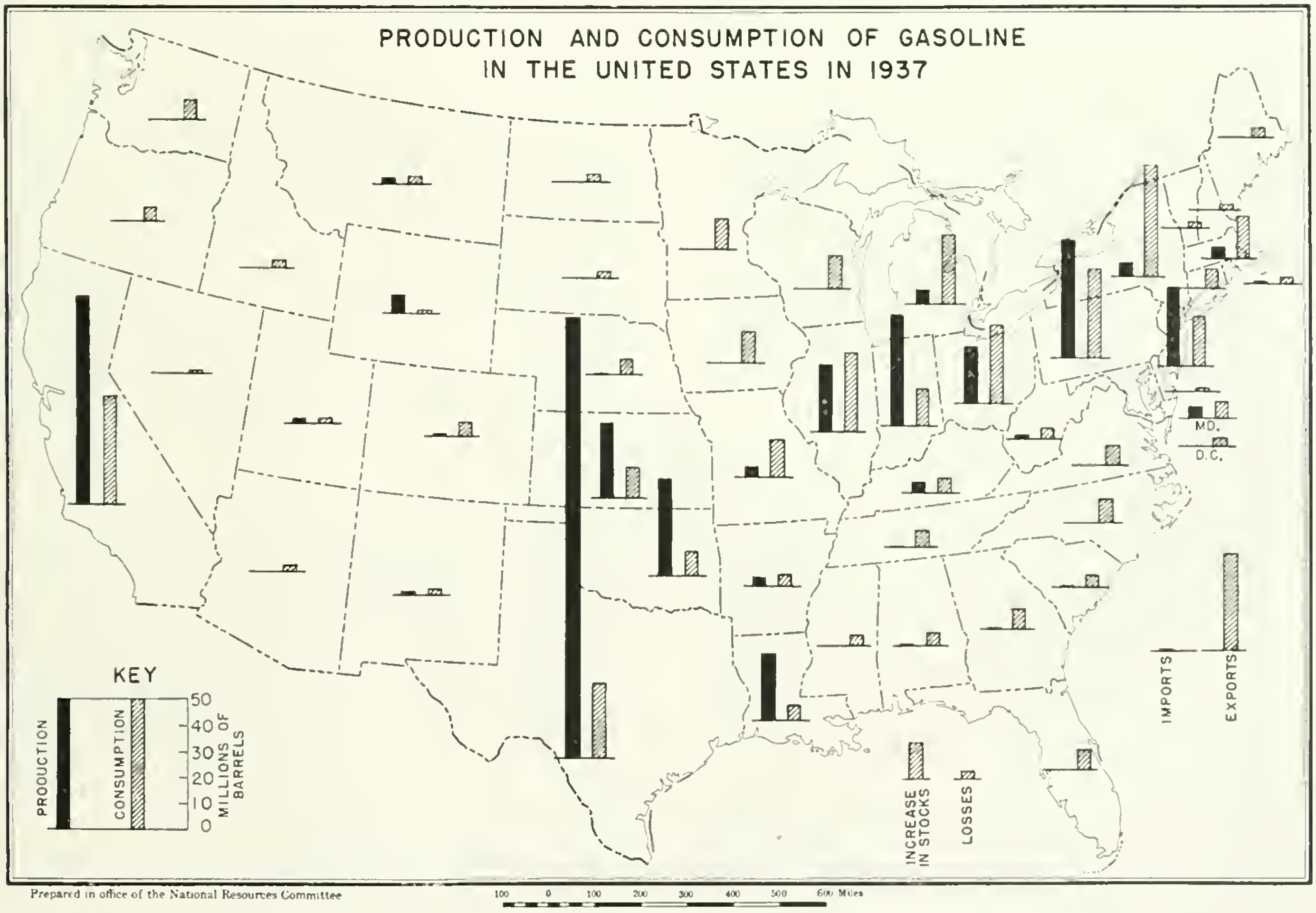
PRODUCTION AND CONSUMPTION OF GASOLINE
IN THE UNITED STATES IN 1937
KEY
PRODUCTION
CONSUMPTION
50
40
30
20
10
0
MILLIONS OF BARRELS
MD.
D.C.
IMPORTS
EXPORTS
INCREASE IN STOCKS
LOSSES
Prepared in office of the National Resources Committee
100 0 100 200 300 400 500 600 Miles

FIGURE 17.

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[16] *Minerals Yearbook, 1938*, p. 877.

[17] *Minerals Yearbook, 1938*, p. 878.

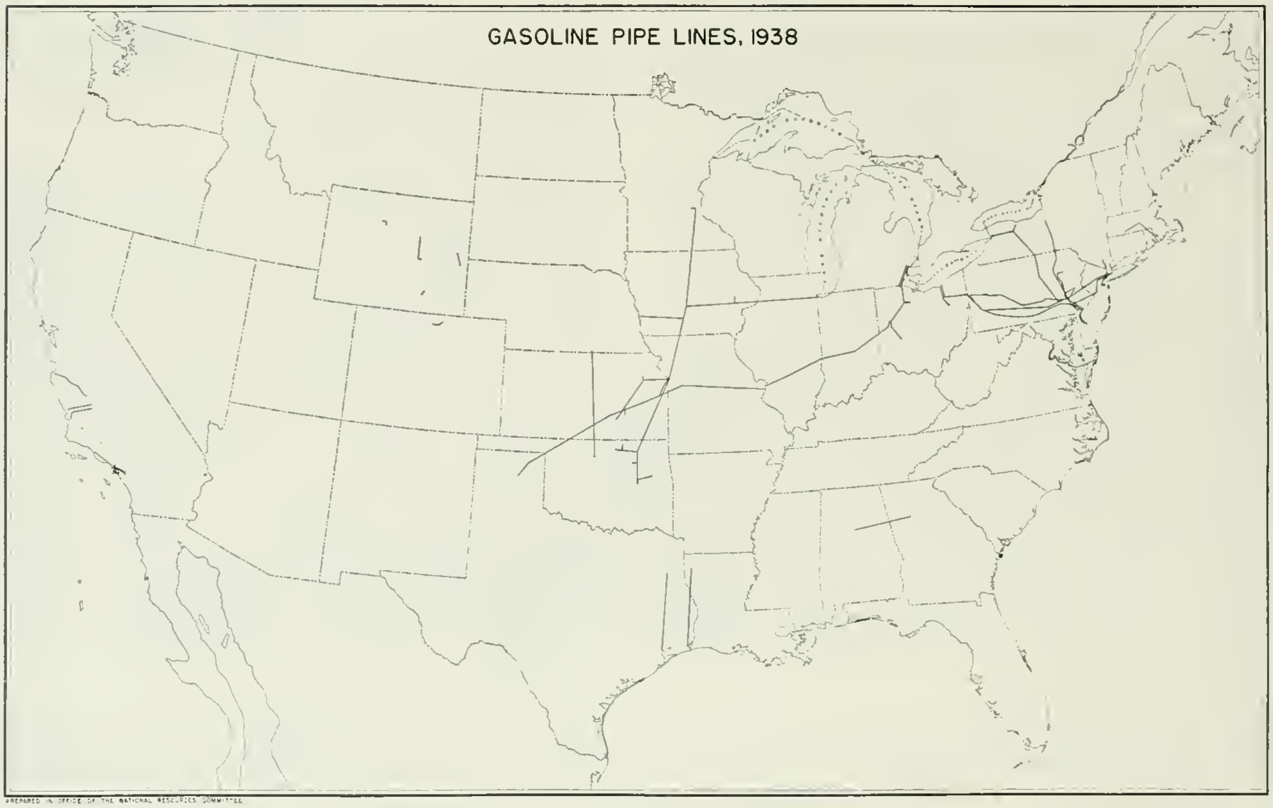
GASOLINE PIPE LINES, 1938
PREPARED IN OFFICE OF THE NATIONAL RESOURCES COMMITTEE

FIGURE 18.

Within the last decade gasoline pipe lines have been constructed from the midcontinent district to the north and east and also to the Texas coast, and from the refineries in the Philadelphia and New York areas to consuming centers in New York, Pennsylvania, and Ohio (fig. 18). These pipe lines have materially reduced the cost of shipping gasoline. Moreover, the expansion of refining capacity along the Gulf coast has resulted in a larger percentage of gasoline shipments being made at lower cost.

Statistics on the transportation of gasoline are not sufficient to indicate accurately the relative importance of the various means of transportation. They are sufficient, however, to indicate the decreasing use of railroads and the increasing use of pipe lines and tankers. A study by the Interstate Commerce Commission[18] indicates that in 1928, the first year in which gasoline figures were reported separately, railroads carried 86.1 percent of total gasoline produced.[19] By 1937 gasoline hauled by tank cars had declined to 53.6 percent.[20] On the other hand, gasoline transported by pipe lines increased from 12 million barrels, or approximately 3 percent of consumption in 1931, to 73.2 millions, or about 14.5 percent in 1937.[21] Barge shipments of gasoline from the Gulf to the east coast region totaled 104.1 million barrels in 1937, which represented 20.7 percent of the domestic consumption, or a somewhat larger share of the domestic consumption than comparable barge shipments in the previous year. For 1937 practically all the remaining 11.2 percent represents gasoline carried by motor trucks.

Natural Gas

Consumption of natural gas is concentrated mainly in or near producing areas and in the urban sections of the Midwest and Upper Mississippi Valley (fig. 19).[22] There is much less difference between producing and consuming areas than in the case of crude oil. The major areas in which consumption exceeds local production are Ohio, with an excess consumption in 1937 of 82 billion cubic feet; the midwestern States, Illinois, Indiana, and Michigan, with an excess consumption of

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[18] Walter M. W. Splawn, "Transportation by Pipe Lines," *Oil and Gas Journal*, September 22, 1938, p. 66.

[19] In 1932 approximately 51 percent of the total traffic in refined products originated on water carriers, approximately 45 on Class I railroads, and about 3.3 on interstate pipe lines. At that time, the volume of refined petroleum products moved by intrastate pipe lines, Class II and Class III railroads, and by motortrucks was very small. Federal Coordinator of Transportation, *op. cit.*, p. 53.

[20] In 1937 approximately 38.4 million tons of "petroleum oils, refined and all other gasolines" (mainly gasoline and kerosene) originated on class I railroads. The traffic was equivalent to approximately 277.5 million barrels or about 50 percent of the 1937 consumption of these products.

[21] The 1937 pipe-line shipments represent an increase of 25 percent over the previous year. *Minerals Yearbook, 1938*, p. 877.

[22] Since production and consumption figures for all States were not available at the time of going to press, the accompanying chart is based on 1936 data.

115 billion; the trans-Mississippi group of States, including Minnesota, Iowa, Nebraska, Missouri, and Kansas, with an excess consumption of 111 billion; and a group of southern States, comprising Arkansas, Tennessee, Alabama, and Georgia, with an excess consumption of 69 billion.[23] Industrial use of natural gas is apparently more important in the midwestern States than in the other areas of deficit production.

Among gas-producing States, high excess production occurs in Texas, with an excess in 1937 of 149 billion cubic feet; Louisiana with 141 billion; and West Virginia with 84 billion. The excess production in Oklahoma, the second State in production in 1937, amounted to 58 billion cubic feet in that year; and in the important gas-producing State of Pennsylvania production roughly balanced consumption at somewhat less than 120 billion.

For distant shipments of natural gas the direction of movement was usually toward the north or the east. The major interstate shipments were from the Panhandle of Texas to the upper Mississippi Valley and toward the east as far as Detroit and Toledo; from Louisiana to adjacent States and as far north as St. Louis and as far east as Atlanta and Macon, Georgia; and from West Virginia into Ohio and parts of Pennsylvania. Less important interstate shipments were made from New Mexico to Texas and Arizona, from Oklahoma to Kansas, and from Texas to Colorado and Wyoming. In addition to these shipments of natural gas there were also important intrastate shipments, especially in Texas, California, Oklahoma, Louisiana, and Pennsylvania. It should be pointed out that in some States where production and consumption are approximately in balance there were, nevertheless, important movements of natural gas into and out of the State. For example, Pennsylvania consumed large quantities of West Virginia gas and at the same time delivered nearly equal amounts to consumers in New York. With respect to California, however, there were no shipments into or out of the State.[24]

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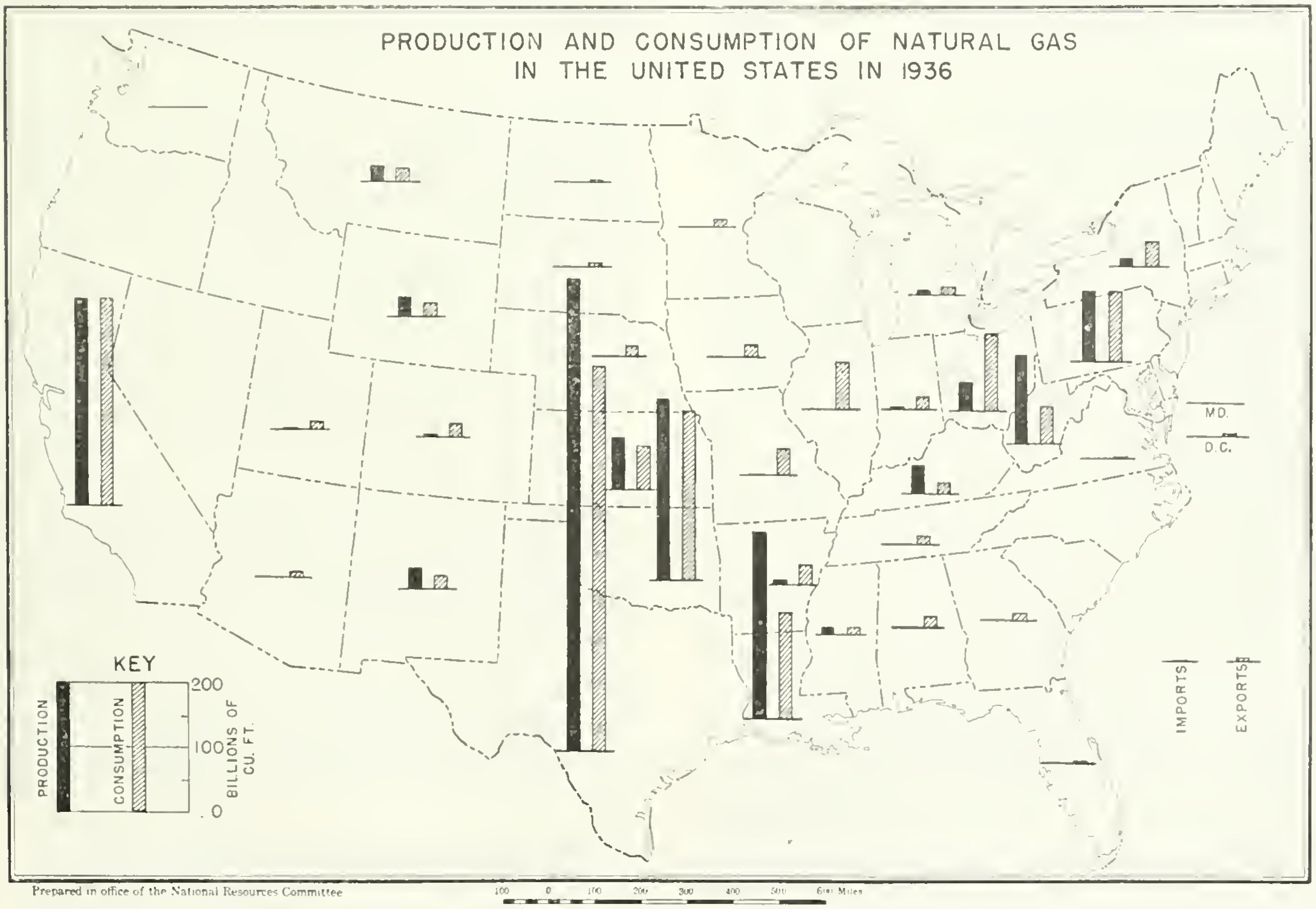
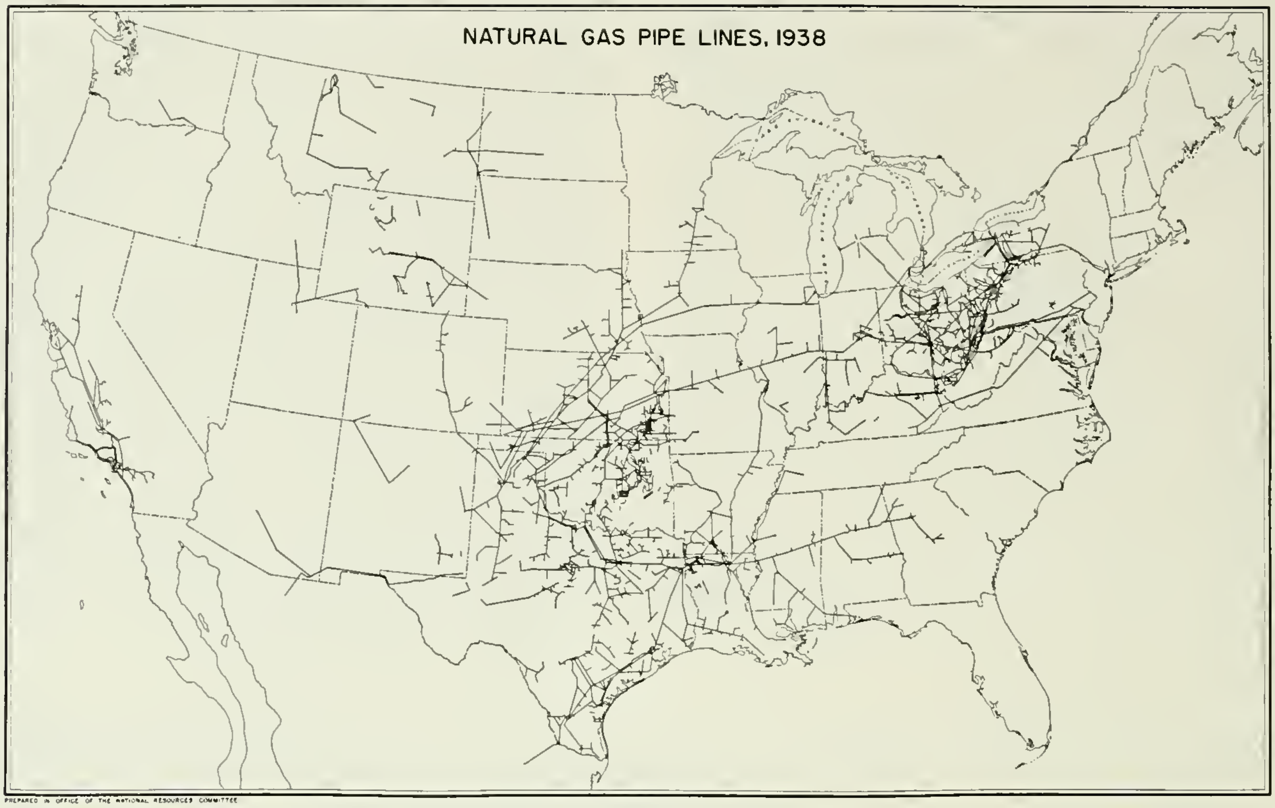
[23] U. S. Bureau of Mines, *Natural Gas Consumption Sets New Record—1937*, Mineral Market Reports, No. M. M. S. 682, December 13, 1938, p. 2.

[24] *Minerals Yearbook, 1938*, pp. 939–942.


PRODUCTION AND CONSUMPTION OF NATURAL GAS IN THE UNITED STATES IN 1936
MD.
D.C.
IMPORTS
EXPORTS
KEY
PRODUCTION
CONSUMPTION
200
100
0
BILLIONS OF CU. FT.
100 0 100 200 300 400 500 600 Miles

Prepared in office of the National Resources Committee

FIGURE 19.



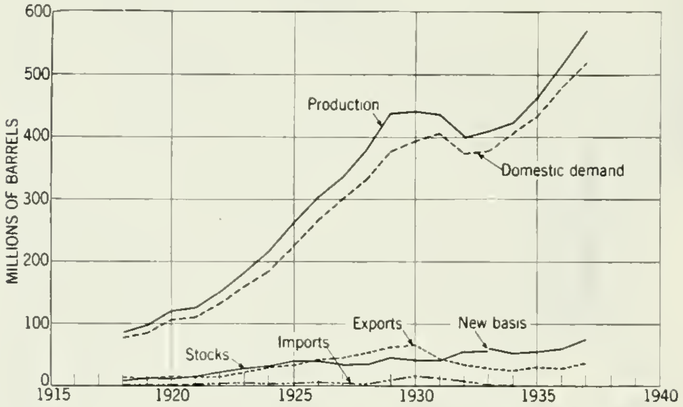
PREPARED IN OFFICE OF THE NATIONAL RESOURCES COMMITTEE

FIGURE 20.

Growth of Consumption of Products of Oil and Gas

Motor Fuel

The domestic demand for motor fuel rose from about 75 million barrels in 1918 to 522 million in 1938 (fig. 21). Only between 1931 and 1932 was there a year-to-year drop in average annual demand. As the accompanying chart indicates, domestic production throughout this period was more than adequate to supply the demand. The peak excess of production above demand came in 1929, although the excess was nearly as great in 1937. Closely related to these excesses in production were the peaks in exports in 1929–30 and in stocks in 1937. Imports of motor fuels are of little importance.



U. S. Bureau of Mines
Minerals Yearbook, 1938

FIGURE 21.—Trends in Production, Domestic Demand, Exports, Imports, and Stocks of Motor Fuel, 1918–37.

Primary causes for the rapid rise in motor fuel demand have been the increases in motor vehicle registrations and the continued growth of motor fuel consumed per motor vehicle in use. At the end of 1918 motor vehicle registrations in the United States were somewhat over 6 millions.[25] Six years later the number amounted to 17.6 millions, and by the end of 1938 it had increased to 29.2 millions.[26] Early data on consumption per car are not available, but from 1924 to 1937 the motor-fuel demand per motor vehicle in use rose from 11.7 barrels to 19.2 barrels.[27] This rise resulted both from the greater use of automobiles and from the more rapid growth of busses and trucks for transportation.

Consumption as motor-vehicle fuel is by far the most important use of gasoline. It is estimated by the

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[25] *Statistical Abstract of the United States, 1937*, p. 363.

[26] *Automotive Industries*, February 25, 1939, p. 209

[27] *Minerals Yearbook, 1937*, p. 1029; *Minerals Yearbook, 1938*, p. 865.

Bureau of Mines that all other uses amount to only 11 percent of the total.[28]

Kerosene

From 1918 to 1933 there was no noticeable upward or downward trend in the domestic demand for kerosene. The peak in demand came in 1925 at 40 million barrels. From 1932 to 1938 domestic demand for kerosene rose from 33.2 million barrels to 56.4 million. Only a small part of this great upswing in demand resulted from the general improvement in business during that period.

In all years the domestic production of kerosene has considerably exceeded demand, although recently the indicated domestic demand has been growing more rapidly than production. In 1936 the excess in production was cut to 4.7 million barrels. Yet in 1937 the excess rose to 10.4 millions despite an increase in demand. Throughout the 1920's there was an excess production of approximately 20 million barrels, practically all of which was sent to foreign markets. After 1926 exports of kerosene were cut drastically and in 1937 amounted to only 9 million barrels, or much less than one-half the average for the 1920's. There has been a slight downward tendency of stocks in kerosene since 1918.

Originally kerosene was used as an illuminating oil. Later on it became important as a fuel for cooking. Within the last few years, however, its use as range-oil fuel has increased rapidly.[29] In 1931 range oil made up 4.5 million barrels out of a total domestic demand for kerosene of 31.3 millions, whereas in 1937 range oil accounted for 31.0 out of 55.0 millions. New England still leads in the consumption of range oil. Owing to the lack of natural gas in that section and to comparatively low prices of oil during the depression,[30] the use there of range oil for room heating, water heating, and cooking has been greatly accelerated. Recent statistics, however, indicate a more rapid growth in its use in other sections of the country.

Fuel Oils

Although detailed figures are not available, the indicated domestic demand of fuel oils rose from roughly 150 million barrels in 1918 to approximately 418 million in 1929 (fig. 22).[31] In 1932 the domestic demand for fuel oil dropped to 308 million barrels and then in 1937 recovered to 442 million, or above the 1929 level. A somewhat more accurate indication can be given of changes in the production of fuel oils. From 1918 to 1929 there was a growth from 174 millions to 449 millions. In 1932 the production of fuel oils fell to 301 millions and then recovered to 457 millions in 1937. The 1937 output of fuel oil represented a yield at the refineries of 38.6 percent of the volume of crude input. These figures make no allowance for crude oil transferred to fuel-oil accounts, which in 1937 amounted to 17 million barrels.[32] Therefore the total domestic supply of gas oil and fuel oil in 1937 was 474 million barrels. In 1938, production of fuel oils was 447 million barrels, and indicated domestic demand was 407 million barrels.

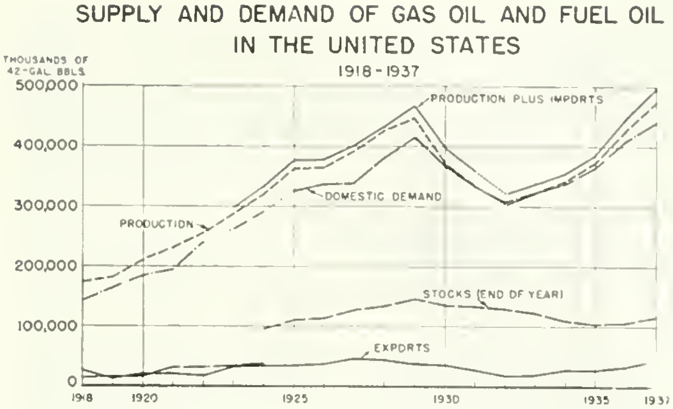

FIGURE 22.

The domestic demand for fuel oils appears to have risen rapidly during the 1920's, but in each year production remained well above demand. From 1930 until 1937, however, the average excess was insignificant. Indeed, the domestic demand was materially closer to domestic production for fuel oils than for other major refined products. The reason lay not in the expansion of demand but rather in the restriction in the amount of crude petroleum used for fuel oils as a result of the rising percentage recovery of gasoline. From 1929 to 1935 the stocks of gas oil and fuel oil, including Cali-

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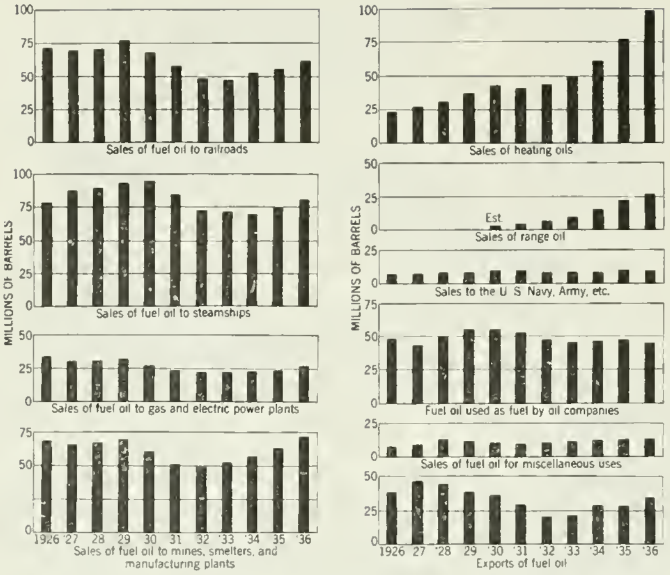
[28] *Minerals Yearbook, 1937*, p. 1030.

[29] In 1932, at a time when the production of and demand for other important refined products were decreasing, the production and domestic demand of kerosene rose for the first time in a number of years; the main reason was the increasing use of kerosene as range oil, primarily in New England.

[30] Coal strikes and threats of strikes had a good deal to do with introduction of range oil.

[31] The Bureau of Mines printed a figure of 142,750,000 barrels as the gas-oil and fuel-oil consumption for 1918; *Mineral Resources, 1924*, pt. II, p. 455. This figure, however, does not take into consideration the transfers of crude oil to fuel-oil supplies, occurring mainly in California, nor does it allow for changes in stocks of these California crude oils.

[32] Much crude oil is burned directly in addition to the crude transferred to fuel-oil accounts in California. In the balance of the country, the consumption of crude petroleum as fuel on producing properties, in operation of pipe lines, and for other purposes including the losses, amounted in 1937 to 19 million barrels. By far the largest portion of this consumption was for industrial purposes other than for oil-producing companies. *Minerals Yearbook, 1938*, p. 821. Figures are available from 1918 to the present, indicating the crude oil used as such plus transfers to fuel-oil accounts and losses. The crude oil covered in these three categories rose from 88.5 million barrels in 1918 to 134.7 million in 1923. The low point comes in 1932 at 12.9 millions, and the 1937 figure amounts to 36.5 millions. It is impossible to indicate how much of the 1923 volume of 134.7 millions is accounted for by direct consumption of crude oil. It seems likely that the consumption of crude petroleum as fuel oil in districts east of California rose from 1918 to 1923 and decreased considerably since then. Refer to American Petroleum Institute, *Statistical Bulletin*, vol. 19, No. 17, March 31, 1938, Form No. 7.



U. S. Bureau of Mines
Minerals Yearbook, 1938

FIGURE 23.—Sales of Fuel Oil and Gas Oil, 1926–36.

fornia heavy crude additions to supplies, dropped from 147 million to 104 million barrels. Another influence tending to lower stocks was the increase in demand after 1932, especially for heating oils and for fuel oils by manufacturing plants. But from the first of May 1937 to the end of October 1938, production of fuel oils exceeded demand, and as a result stocks rose from 94 million barrels to 154 million.

Fuel oils are consumed in numerous markets both industrial and domestic (household). The largest use of fuel oils is for heating, mainly domestic. This source of demand has developed rapidly only since 1932 (fig. 23).[33] Other major changes in the use of fuel oil since 1926 are the decrease in consumption by railroads, steamships, gas and electric public utilities, and oil companies themselves. Moreover, exports have tended to decline. A significant cyclical swing in consumption is noticeable in the sales to mines, smelters, and especially to manufacturing plants, and also to railroads and steamships. The consumption requirements of these two transport groups still remain very important. The question of the relative efficiency in the use of fuel oils is discussed later.

Perhaps the most significant change relating to fuel oil in the last decade has been the rapid growth of consumption of gas oil and distillate fuel oil. From 1931 to 1937, production of these lighter oils increased from 84 million to 147 million barrels, in comparison with a rise for residual oils from 253 million to 310 million barrels.[34] These changes reflect the upward trend in the yield of light oils and the corresponding decline in the yield of heavy oils. This tendency has been dictated by the desire of refiners to produce larger quantities of the more profitable light oils. Among the types of distillate fuel oils, domestic furnace oil is of outstanding importance. The demand for this oil has increased with the installation of oil burners, especially in northern States. Estimated heating-oil consumption of domestic oil burners rose from 0.8 million barrels in 1921 to 81.2 million in 1937.[35] In the latter year the consumption of heating oils by domestic burners amounted to 70 percent of the total heating-oil sales.[36] Moreover, from 1930 to 1936 the consumption of domestic heating oil grew nearly eight times as rapidly as the consumption of gasoline.[37] Diesel fuel oil—also a distillate—is being consumed in greater quantities by motor trucks, tractors, and railroads.[38] The production of this oil amounted to 22.2 million barrels in 1937.

A major proportion of fuel oils is produced in Texas and California. In 1937 the Texas production totaled 139 million barrels—113 million in the Gulf coast district alone. California in that year produced 116 millions, the east coast district 84 millions, and Indiana-Illinois 42 millions. In addition, California contributed all of the crude oil which was transferred to fuel oil supply.

Lubricants

From 1918 to 1929 there was a moderate upward trend in the domestic demand for lubricants. According to the Bureau of Mines, the indicated domestic demand rose from about 14 million barrels to somewhat less than 24 millions. In no year was domestic demand more than about three-fourths of domestic production. In fact, domestic production increased more rapidly than demand. Most of the difference was exported, although stocks of lubricants increased. Exports reached a peak in 1928, and stocks in 1930. After 1929 the domestic demand shrunk greatly, falling from 23.6 million barrels in 1929 to 16.6 million in 1932. By 1937, however, it had practically recovered to the 1929 level.[39] The quantity of exports in that year also equaled the 1929 volume.

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[33] Domestic heating requirements for fuel oil amounted to only 6.9 million barrels per year on the average during the 1926–31 period. In 1936 the total was 69.4 million barrels. H. A. Breakey, *Petroleum Investigation, 1934*, p. 126; also special tabulation from Department of Statistics, American Petroleum Institute. In the 1926–31 period the consumption of fuel oils by steamships, including tankers, averaged 88 million barrels per year; manufacturing and mining uses averaged 74 millions; railroads, 69 millions; gas and electric power plants, 30 millions. Among manufacturing industries the most important consumer of fuel oil was iron and steel products, which averaged 17 million barrels during this period.

[34] *Mineral Resources, 1931*, pt. II, pp. 633–634.

[35] American Petroleum Institute, Department of Statistics, special tabulation; *American Petroleum Institute Quarterly*, July 1938. The number of oil burners in operation at the end of 1920 was 12,500. New installations increased rapidly, and at the beginning of 1938 the number of burners in operation was 1,555,000. Also see U. S. Bureau of Mines, *Fuel Oil and Kerosene Sales Established New Records in 1937*, Mineral Market Reports No. M. M. S. 708, Feb. 16, 1939, p. 3.

[36] *Ibid.*

[37] American Petroleum Institute, Department of Statistics, Special Tabulation; *Minerals Yearbook, 1937*, p. 1029.

[38] Diesel motor sales rose from motors with 400,000 horsepower in 1930 to motors with more than 2 million horsepower in 1937, *Oil and Gas Journal*, March 10, 1938, p. 31.

Between 1929 and 1937 the domestic demand for lubricants for trucks and busses rose relatively more than did the demand for lubricants for passenger cars. The demand for stationary machinery lubricants was 10 percent less in 1937 than in 1929. During prosperity about half the consumption of lubricating oil is for automotive uses. In a depression year the industrial demand is much more restricted. Nearly half of the domestic production of lubricating oils occurs in the east coast and Appalachian refining districts.

Other Refined Products

From 1923 to 1928 the domestic demand for paraffin wax was upward. Approximately 200 million pounds of wax were consumed in 1918 in comparison with the 1928 consumption of 300 million pounds. Exports exceeded the domestic demand in every year from 1918 through 1931. Part of the rise in exports after the war was facilitated by the drop in stocks. Since 1931, however, domestic demand for wax has in every year exceeded exports. In 1937 production amounted to 521 million pounds, or more than 100 million pounds less than the 1926 peak. Imports of wax have been of minor importance. Well over half the wax is produced in the east coast and Appalachian refining districts, primarily from Pennsylvania crude.[40]

After 1918 the domestic demand for asphalt expanded rapidly, the 1929 volume being nearly 3.5 million short tons, or six times the 1918 sales. During the depression the demand fell sharply, but by 1937 had risen to 4.2 million short tons. Since 1932 the construction of highways has led to a sharp rise in the output of asphalt as well as road oil. The increased output of asphalt was a reflection also of a mild expansion in housing construction. In 1937 approximately 40 percent of the petroleum asphalt manufactured in the United States came from east coast refineries. These use some imported crude, chiefly from Venezuela and Mexico. About 36 percent of the 1937 production of petroleum asphalt was made from these foreign crudes.

Petroleum coke production rose from about 0.5 million short tons in 1918 to approximately 2.0 million short tons in 1931. Since 1931 production has tended to decrease. In 1937 production was 1.3 million short tons—a domestic demand of 1.15 millions and exports of 0.16 million. Stocks at the end of that year equaled nearly 30 percent of production.[41] Petroleum coke is one branch of petroleum refining not characterized by an upward trend.

Many minor products are created in the refining of crude petroleum. Crude oil supplies a sizable proportion of the raw material for chemical products, such as ethyl alcohol, ethylene, acetylene, and organic acids, and thus indirectly enters into the making of such commodities as rubber substitutes, plastics, explosives, antifreeze materials, solvents, disinfectants, perfumes, soaps, and medicines.[42]

Consumption of Natural Gas by Uses

Since natural gas is not stored and since imports and exports are of no significance, marketed production is essentially the same as total consumption.[43] Marketed production is less than actual production by the amount of natural gas which is wasted either in production or in distribution.

Since the early history of the natural-gas industry, industrial uses have been more important than domestic and commercial uses. In 1906, for example, 275 billion cubic feet of natural gas were consumed by industrial users and 110 billion cubic feet by domestic and commercial users. Both types of demand increased more or less regularly until 1930, in which year the industrial use was 1,565 billion cubic feet and the domestic and commercial consumption 377 billion cubic feet. Industrial consumption dropped considerably in the depression and recovered to an all-time peak of 1,951 billion cubic feet in 1937.[44] On the other hand, total domestic and commercial use rose in every year after 1930 except in 1933 and reached an all-time peak of 489 billion cubic feet in 1937. From 1906 to 1937 industrial demand multiplied by about seven, whereas domestic and commercial demand multiplied by more than four. The high rate of increase in industrial consumption resulted in part from the fact that production of natural gas was increasing more rapidly than the growth in the number of consumers within the distribution range of producing fields. Consequently the gas had to be used in the fields or in adjacent territories for industrial purposes or wasted. By contrast, the growth in domestic and commercial consumption during the 1930's is related to the extension of pipe lines into new and more populous territories in the Midwest and also to the high rate of growth in commercial requirements.[45]

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[39] *Minerals Yearbook, 1938*, p. 889.

[40] *Ibid.*, pp. 889–890.

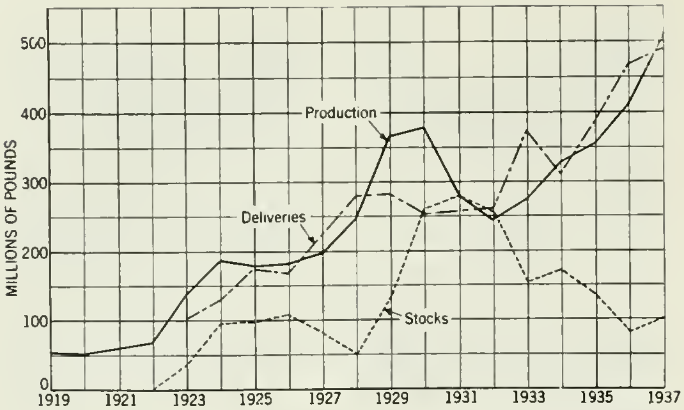
[41] *Ibid.*, p. 893.

[42] For a list of products of petroleum refining, see American Petroleum Institute, *Petroleum Facts and Figures, 1937*, table opposite p. 108.

[43] In 1937 marketed production of natural gas in the United States amounted to 2,448 billion cubic feet, and total domestic consumption was 2,443 billion cubic feet. The slight difference is made up of the excess of exports over imports. In 1937, exports, mainly to Mexico, were 4.9 billion cubic feet. Imports from Canada were 0.3 million cubic feet. U. S. Bureau of Mines, *Natural Gas Consumption Sets New Record in 1937*, Mineral Market Reports No. M. M. S. 682, December 13, 1938, p. 2.

[44] *Ibid.*, p. 1.

[45] Data for consumption by domestic and commercial users separately were not available until 1930. From that year until 1938 the increase in consumption by commercial users was 46 percent in contrast with an increase for domestic users of 23 percent.



U. S. Bureau of Mines
Minerals Yearbook, 1938

FIGURE 24.—Production, Stocks, and Deliveries of Carbon Black, 1919–37.

Figures on value of gas at points of consumption show that industrial use is marginal, although it must be noted that industrial sales probably include less transportation. In 1937 the value for industrial use averaged only 10.2 cents per thousand cubic feet, whereas that for domestic use averaged 72.3 cents and that for commercial use 47.5 cents. Treating of natural gas for motor fuel was initiated in 1903 and became commercially important about 1910. In 1914 only 4 percent of marketed production was treated for recovery of gasoline, but in the next 2 years the proportion jumped to 54 percent. The practice of recovering natural gasoline rose steadily, and in some years since 1928 more gas was treated than marketed, because part of the residual gas was blown into the air.[46]

All industrial uses of natural gas expanded after 1919. The greatest expansion appears to have occurred in making carbon black. The volume of gas used for this purpose in 1937 was 6.8 times the 1919 volume. For field use, including drilling and pumping, consumption multiplied by 4.1 and, for all other industrial uses, by 3.4. Gas used in making carbon black accounted for 10 percent of industrial uses in 1919 and 18 percent in 1937.[47]

Within the last decade more information on industrial consumption of natural gas has been collected. Consumption of natural gas by petroleum refineries reached a peak of 123 billion cubic feet in 1927 (rising from 88 billion cubic feet in 1925); the figure was 113 billion in 1937.[48] Among industrial uses the rate of growth was greatest for electric public utilities, the rise being from 63 billion cubic feet in 1927 to 171 billion in 1937. Between the same years consumption by carbon-black plants approximately doubled, rising to 341 billion cubic feet in 1937. In Portland cement plants there was an expansion of natural-gas consumption of roughly 70 percent between 1927 and 1937.

Carbon Black and Natural Gasoline

Aside from the direct consumption of natural gas as fuel, the two major products from it are carbon black and natural gasoline. The demand for carbon black has grown roughly at the same rate as production. As the industrial uses of carbon black have expanded, a rising volume of natural gas has been consumed in its production. The accompanying chart indicates that in 1937 there were produced approximately 500 million pounds of carbon black, or 20 times the 1919 output. Although production greatly exceeded deliveries in 1929 and 1930, deliveries have exceeded production in most subsequent years. Exports are included in deliveries and in 1937 amounted to 184 million pounds out of total sales of 490 million pounds. Since 1930 a larger proportion of carbon black has been shipped to foreign countries; exports in 1937 were about 2½ times the 1930 quantity.

The largest and most important use of carbon black is in the manufacture of rubber products. In 1925 the rubber companies consumed 86 million pounds of carbon black, or 65 percent of domestic consumption. Since then an increasing percentage of output has been sold to rubber companies, and in 1937 they accounted for approximately 88 percent of domestic consumption (or 55 percent of total deliveries). The rapid rise of the carbon-black industry can be interpreted largely in terms of the greater use of carbon black in an industry which itself is characterized by an upward trend. Carbon black is also used in the production of ink and paint and for many miscellaneous industrial purposes. These other markets, however, have not grown since 1925, and in 1937 the sales to ink and paint companies were nearly 30 percent less than they had been in 1925.

Of total output of carbon black, about 80 percent occurs in the Texas Panhandle and half the remainder in Lousiana.

Figures on the domestic demand for natural gasoline are not available. Consumption, however, appears to have followed rather closely to production. The industry began about 1910 and reached a peak output at 2.2 billion gallons in 1929. During that period the production of natural gasoline was growing relatively more rapidly than the output of crude petroleum (fig. 25). Since the great depression, however, the production of natural gasoline has failed to reach the 1929–30 level.

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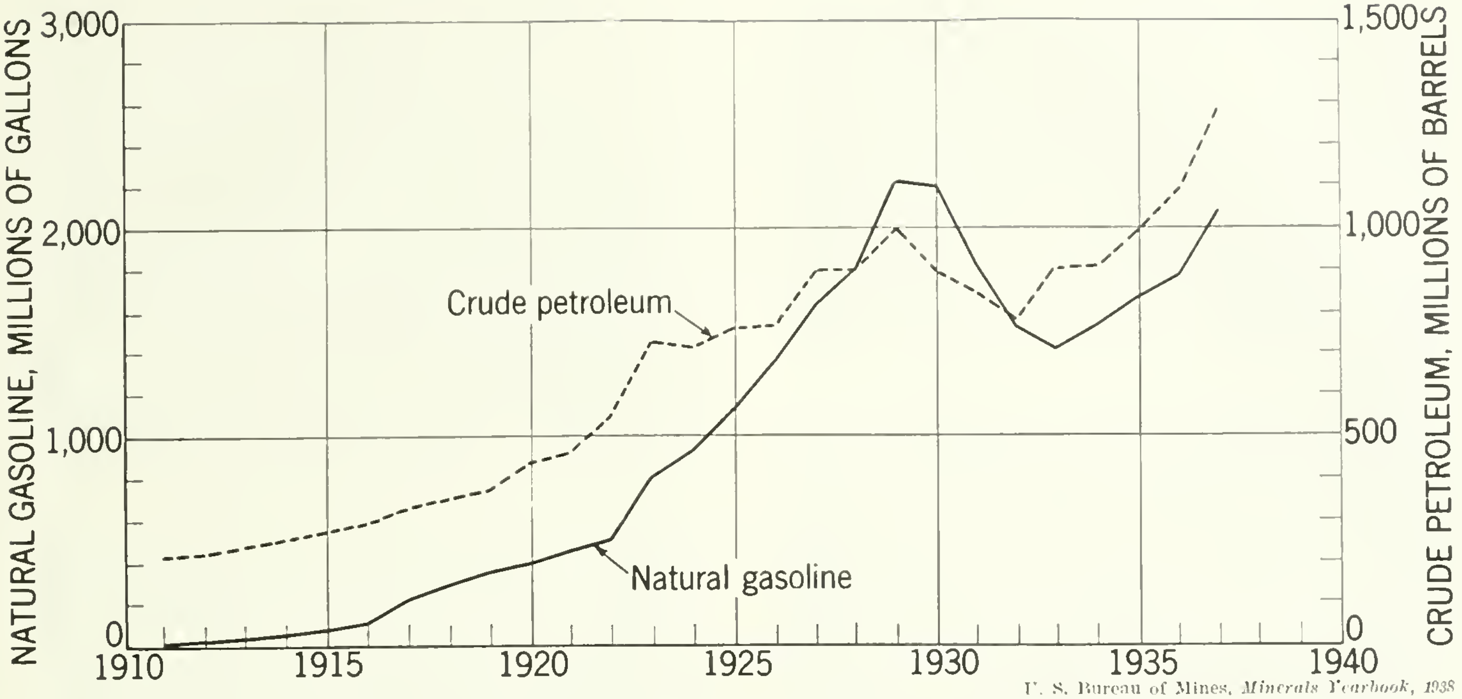
[46] Residue gas is more likely to be wasted where natural gasoline is the major product, as in the Texas Panhandle. *Mineral Resources, 1925*, pt. II, p. 133; *Mineral Resources, 1931*, pt. II, p. 350; *Minerals Yearbook, 1938*, p. 908.

[47] From 1919 to 1937 the proportion of the industrial consumption accounted for by field use remained at 35 percent and the proportion for all industrial uses other than carbon black or field use fell from 55 percent to 47 percent.

[48] U. S. Bureau of Mines, *Natural Gas Consumption Sets New Record in 1937*, Mineral Market Reports No. M. M. S. 682, Dec. 13, 1938, p. 2.



U. S. Bureau of Mines, *Minerals Yearbook, 1938*

FIGURE 25.—Annual Production of Natural Gasoline and Crude Petroleum, 1911–37.

Several factors have contributed to this condition. In the early thirties decreased crude production and proration orders curtailing production of "wet" gas reduced the available supply of raw material. The main reason, however, has been the growth of the stabilization process, which removes the more volatile fractions from the natural gasoline. A large percentage of unstabilized natural gasoline, as much as 82 percent of consumption in 1937, is used by petroleum refineries for blending with other gasolines. Although the major demand is still that of refineries, an increasing percentage of stabilized natural gasoline has been shipped directly to jobbers and retailers. In 1937 direct sales represented 7 percent of the indicated demand.[49] Natural-gasoline refiners attempted to increase direct sales in order to offset the decreasing refinery demand brought about by expansion of cracking activity and the refining of lighter-gravity crudes.

Production of natural gasoline is scattered throughout the oil- and gas-producing districts, the more important fields being Texas Panhandle, East Texas, Kettleman Hills, and Oklahoma City.

The more volatile constituents removed from natural gasoline are marketed as liquefied petroleum gases. Sales of these gases rose from 1.1 million gallons in 1927 to 141.5 million in 1937. Consumption is still growing at a rate of roughly 30–40 percent per year; for example, in 1937 sales of liquefied gases for industrial fuel and chemical manufacturing were about 28 percent above the 1936 record.[50] These uses comprised nearly 50 percent of the total consumption in 1937. Domestic consumption of "bottled gas" accounted for 30 percent; industrial combustion engine fuel for 12 percent; and gas manufacturing for 8 percent. Total deliveries were composed about equally of propane-butane mixture, propane, and butane.

Competitive Gains from Other Fuels

Interfuel competition includes the market relations of liquid and gaseous hydrocarbons with coal and other sources of energy and, in addition, the relations among petroleum, natural gas, and their various products. The extent to which one fuel can take over part of the market of another fuel depends upon differences in convenience, quality, and cost. Much of the gain in consumption by a given fuel, however, may result from the more rapid growth of its availability and not from a loss to other fuels; in other words, the gain is relative. Indeed, the absolute increase in consumption of oil and gas products has occurred mainly in noncompetitive fields, or at least in uses where the possibility of substitution was indirect.[51] Competitive gains, it should be pointed out, are sometimes not a result of a general tendency but rather of cyclical changes in comparative prices or of accidental discoveries of new fuel supplies.

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[49] *Minerals Yearbook, 1938*, p. 951.

[50] *Minerals Yearbook, 1938*, p. 958.

[51] A. T. Shurick, "King Coal Still Rules 75% of His Domain, Though Credited With but 54%," *Annalist*, April 2, 1937, p. 516. R. T. Goodwin, "Fuel Oil Production and Use," *Oil and Gas Journal*, November 18, 1937, p. 56.

Thus, in a period of overproduction of petroleum, prices of its products are likely to fall relatively to those of coal, and for a time these products will take over part of the fuel requirements heretofore satisfied by coal. The costs of a fuel are determined by both mining and distribution expenses. In the main, the decrease in the price of petroleum products since 1930 has resulted from lower production costs, although the shift of production toward the Gulf coast has allowed the use of more economical means of transport to North Atlantic markets.

Gasoline

For the most part, gasoline consumption has expanded at the expense of coal consumption only in an indirect manner. For passenger traffic the automobile, to an important extent, has displaced the railway, and for a large volume of the most profitable freight the motor truck has been substituted for the freight train. About half the volume of motor fuel is consumed on rural highways. Within the city the competition of automotive transport has resulted in a restriction of streetcar traffic and of drayage and haulage by animal power. Street railways are indirect consumers of coal or occasionally water power. Approximately 89 percent of gasoline is consumed as motor fuel—47 percent within the city and 42 percent on the highways.[52] Of the nonautomotive uses, agriculture is the most important. On farms, gasoline has to some extent been substituted for kerosene as an illuminant and as a fuel for tractors and some types of stationary motors. In construction, including highway building, gasoline consumption has been increasing. For railroad uses there has been some substitution of gasoline for coal, in that motor trains have been introduced for local traffic, especially on western and southern lines. The upward trend in consumption of gasoline by railroads reached in 1934 a peak of approximately 1 million barrels, a comparatively insignificant amount. In part the rising consumption of motor gasoline by the United States Navy represents a substitution of gasoline for coal. To the extent that airplanes have taken over passenger traffic from railroads, gasoline has been substituted for coal. From 1932 to 1938 consumption of aviation gasoline rose from about 54 million to 98 million gallons.[52a]

Kerosene

A large percentage of kerosene is now used as range oil. Since 1932, this oil has been displacing coal and wood in the firing of cookstoves and ranges, especially in New England, and recently in the Middle Atlantic States as well. At the present time, the major advantage of range oil over wood or coal is convenience of use, although, when this oil first began to replace coal in New England in the early 1930's, range oil was actually at times cheaper than coal, owing to the depressed condition of markets for petroleum products.[53] This oil also has been substituted for natural or manufactured gas for use in cooking, hot-water heating, and room heating, especially where part-time heating is adequate. The fuel classified as range oil is either a pale yellow kerosene or No. 1 fuel oil, a high-grade distillate.[54] As an illuminant, kerosene is still used in rural areas although, by and large, it has been displaced by electricity or gasoline.

Fuel Oil

In some of its uses, light fuel oil is in direct competition with coal and natural gas. For 1929, it has been estimated, about one-quarter of the consumption of all fuel oil was directly competitive with coal.[55] Preference for fuel oil instead of coal is based mainly on considerations of convenience. Furnace tending is largely obviated, and with oil burners it is possible by automatic or semiautomatic control to maintain predetermined temperatures. In many parts of the country the consumption of fuel oil represents a luxury demand because of the extra cost which equipment and oil entail. Yet the greatest gain in the last decade occurred in household use. According to Bureau of Mines reports, the consumption of domestic heating oil rose from 5.0 million barrels in 1924 to 81.2 million in 1937. There was a rise in the domestic use of natural gas and coke and a decline in the domestic consumption of anthracite and probably bituminous coal.[56] Between 1929 and 1936 the importance of heating and range oils in the total requirements for anthracite, briquettes, coke, and oil in States north of the Potomac rose from 6.9 percent to 27.5 percent.[57] For Massachusetts, figures on total fuel needs indicate that from the year 1926–27 to the year 1933–34 there was an actual, though slight, increase in the consumption of bituminous coal, including briquettes and manufactured gas, and that the increase in consumption of fuel oil (and also coke) resulted partly from the expansion in total consumption of fuel and partly from the restriction in use of anthracite.[58]

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[52] Statement of H. A. Breakey and F. L. Carmichael, U. S. Bureau of Mines, *Petroleum Investigation, 1934*, p. 118.

[52a] W. T. Ziegenhain, "Aviation Gasoline," *Oil and Gas Journal*, November 3, 1938, p. 10.

[53] U. S. Bureau of Mines, *Mineral Market Reports No. M. M. S. 600*, October 26, 1937, p. 3.

[54] *Ibid.*

[55] F. E. Berquist and Associates, *Economic Survey of the Bituminous Coal Industry under Free Competition and Code Regulation*, National Recovery Administration, Division of Fuel, March 1936, p. 25.

[56] *Minerals Yearbook, 1938*, p. 758.

[57] *Ibid.*, p. 755. Data on consumption of bituminous coal within this market are not available. The relative importance of anthracite in the incomplete total fell from 88.9 percent in 1929 to 66.5 percent in 1936. There was an increase of 3.5 percent to 7.0 percent in the consumption of coke.

The commercial consumption of heating oil has expanded materially since 1921, but not so rapidly as the domestic use. In 1921 commercial burners consumed more than 90 percent of the total heating oil, whereas in 1937 commercial burners accounted for only 30 percent of the total. Yet, in the meantime, commercial consumption had increased from 9 million barrels to 35 million barrels. It is clear that this increase in consumption of light oils for heating hotels, apartment houses, and office buildings also represents in part a replacement of coal.[59]

Diesel oil, one of the distillate fuel oils, has been adopted for use by ships, railroads, and trucks. Since 1914 a large percentage of the new ships have been equipped with Diesel motors. Moreover, in old ships oil engines have been installed in place of steam engines.[60] The total world tonnage of iron and steel merchant ocean-going vessels of 2,000 gross tons and over amounted to 49,590,000 gross tons at the end of 1937. Of this tonnage, over 12 million tons were driven by Diesel motors. For the United States merchant fleet, ships with 537,000 gross tons out of a total of 7,791,000 gross tons were motor driven.[61] The shift to Diesel fuel was rapid between 1920 and 1930. In the United States merchant fleet a large percentage of the motor vessels were tankers. Bunkering of vessels is by far the largest use of Diesel oil; in 1937 vessels consumed 13,494,000 barrels.[61a]

High-speed passenger trains have changed over to Diesel fuel rapidly since 1936. During 1937 railroads accounted for 610,000 barrels of Diesel oil. The great advantages of fuel oil are mainly its cost, cleanliness, and high-energy content per unit of weight, as a result of which fueling is required less often than with coal. (Similar considerations apply to the use of Diesel oil by passenger ships.) In some parts of the country, the use of Diesel oil in locomotives is said to result in a great saving in operations, once the new type of locomotive is installed. Mr. Ralph Budd, president of the Burlington lines, reported in 1937 that with Diesel oil the cost per train-mile for locomotive maintenance, locomotive fuel, and lubricating oil averaged only 4.84 cents; whereas, for coal-steam-drawn trains of the same capacity, the cost per locomotive-mile was 28.98 cents.[62] Consequently, these users of fuel oil are not likely to return to coal unless there is a great increase in price. To the extent that Diesel oil is being used by motor trucks it is encroaching on the market for gasoline.[63] The same shift may occur in connection with air transport.

Within the past few years, the United States Navy requirements for Diesel oil have increased. To a certain extent, then, Diesel oil has displaced gasoline and fuel oil. In the fiscal year 1938, the United States Navy consumed about 235,000 barrels.[64] For this use considerations of convenience and quality undoubtedly far outweigh costs.

Within the last decade light fuel oils also have been used to a considerable extent by tractors and other internal-combustion engines instead of gasoline and kerosene. One of the higher grade distillate oils, gas oil, is still used to some extent, especially in California, for its original purpose, that is, the manufacture of gas, although its use decreased considerably after the laying of a natural-gas pipe line to San Francisco in 1928.

Heavy fuel oils include residual oils either straight or blended with distillates. Much of these oils sell in a highly competitive market in competition with coal and natural gas, where the chief interest of the consumers is to obtain the greatest heating value at the lowest net cost. Consequently competitive gains over other fuels obtained during the period of low oil prices may be held only so long as the price remains relatively low. Oftentimes the large volume of heavy fuel oil on the market is an unavoidable consequence of trying to market directly an excessively large crude-oil output or of producing a large quantity of gasoline, and not of any error in gaging the demand for heavy fuel oil itself.

Major use of residual fuel oils is by marine vessels, either merchant or naval. This type of oil is burned underneath boilers to raise steam, and, mainly because of its convenience advantage, it has taken over a large percentage of the marine market for fuels. In 1929 the total fuel consumption for marine use was about 99 million barrels of fuel oil and 8 million tons of bituminous coal. On an energy basis—one ton of coal being equivalent to four barrels of fuel oil—it appears that fuel oil had three-fourths of the market.

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[58] In terms of millions of net tons of coal equivalents the changes were: anthracite, 5.2 to 3.1; bituminous, 0.7 to 0.9; coke, 0.5 to 1.3; oil, 0.3 to 2.6; total, 6.7 to 7.9. If the coke figures are added to the bituminous figures, there was a considerable expansion in the use of bituminous coal. W. C. Trapnell and Ralph Ilsley, *The Bituminous Coal Industry with a Survey of Competing Fuels*, Federal Emergency Relief Administration, 1935, p. 111.

[59] American Petroleum Institute, *Petroleum Facts and Figures, 1937*, p. 35.

[60] In 1914, 60 American ships with 195,000 gross tonnage used oil engines; whereas, in 1931, 1,645 with 8,600,000 tons were equipped with oil engines. Figures from the United States Bureau of Navigation, printed in *Petroleum Facts and Figures, 1937*, p. 30.

[61] *Semi-annual Report No. 1100* of the U. S. Maritime Commission, Division of Research, p. 1.

[61a] U. S. Bureau of Mines, *Fuel Oil and Kerosene Sales Established New Records in 1937*, Mineral Market Reports No. M. M. S. 708, February 16, 1939, p. 4.

[62] Mr. Budd discusses other advantages of Diesel motor drawn trains. It is also maintained that Diesel-operated trains are able to maintain schedules better than steam-operated trains. *Oil and Gas Journal*, November 4, 1937, p. 10.

[63] Charles F. Kettering, vice president of General Motors Corporation, reports that Diesel motors will be introduced very rapidly in commercial vehicles within the next few years, *ibid.*, p. 9.

[64] Henry D. Ralph, "Defense Plan Will Require High Octane Gasoline," *Oil and Gas Journal*, January 19, 1939, pp. 8 and 98.

The division of consumption in 1929 was as follows

	Coal, million tons	Fuel oil, million barrels
Ships in foreign trade	4.3	51
Navy for ships and yards	.6	7
Ships in domestic trade	3.5	41
Total	8.4	99

National Industrial Conference Board, *The Competitive Position of Coal in the United States, 1931*, pp. 118-119; also presented in W. C. Trapnell and Ralph Ilsley, *The Bituminous Coal Industry with a Survey of Competing Fuels*, Federal Emergency Relief Administration, 1935, p. 143.

Oil can be stored in oddly shaped tanks built wherever desirable within the ship and can be loaded more quickly than coal. Moreover, a ship can carry a larger heat value in fuel oil than in coal, and thus in many cases is able to fuel in an American port for a round trip. The greater cleanness of oil-firing contributes to comfort, especially on passenger ships.[65] Consequently, cost may not even be the major determinant in deciding what fuel to use for marine service. Oil is so advantageous for steamship requirements that there is a question whether coal is an effective competitor in that field. Approximately 22 percent of the fuel oil was consumed by steamships,[66] including naval vessels, in 1936. Much of the oil used by the Navy is residual oil blended with distillates.[67] The importance of bunker oil in marine use is notably greater for American vessels than for foreign vessels. In the United States merchant marine at the end of 1937 approximately 7 million of 8 million gross tons of iron and steel, merchant, ocean-going ships were driven by oil-fired boilers and only 0.8 million tons by coal-fired boilers; whereas in the entire world merchant marine coal and heavy oil were of about equal importance in operating steamships—for each, ships of about 19 million gross tons out of a total of 50 million gross tons.[68]

Within the last decade some electric power plants have shifted their fuel requirements from coal to heavy fuel oil, though recently in the Far West there has been some shifting from oil to water power. From 1920 to 1932 there was little change by electric power plants from coal to oil. Since that depression year, however, the use of oil has expanded much more rapidly, in part no doubt as a result of severely depressed prices of fuel oil.[69] Yet comparatively higher prices of fuel oil in 1937 did not lead to any material restriction in the use of oil by these power plants. In the manufacturing of gas, less fuel oil was consumed in 1935 than in 1920. This result is, in part, attributable to the downward trend in the manufactured-gas industry. After 1926 the restriction in the use of fuel oil for making gas was greater than the decrease in use of bituminous coal and coke but very much less than in that of anthracite.[70]

As railroad fuel, the consumption of residual oils reached a peak in 1929 (fig. 23), although the lack of complete recovery in 1937 reflects the drop in traffic rather than any shift back to coal. Relative use of fuel oil actually increased between these years.[71] The rapid expansion of heavy fuel oil consumption in New Jersey reflects the increased use of this fuel in shipping, manufacturing, and heating. From 1929 to 1937 the consumption of all fuel oils in New Jersey rose from 22.5 million barrels to 44.0 million barrels.[72]

Other minor uses of residual fuel oil show some competitive gains. To some extent this heavy oil has been used for commercial and industrial heating. It also has been substituted for gas oil in the manufacture of gas, particularly within the last few years, because the price of the lighter oils has increased relative to that of the heavy oils.

Other Refined Products

Still gas, or refinery gas burned under stills, is in some cities mixed with manufactured or natural gas and in other cases used directly for distribution by public utilities to industrial or domestic consumers. To some extent still gas, therefore, is competitive with natural or manufactured gas. Within the past few years petroleum coke, a customary product of the cracking process, has been substituted somewhat for other fuels. Lubricating oils are not used as a fuel, and in any event there is little possibility that these oils can be displaced by competing products; animal oils as a means of lubricating machinery were discarded long ago. Nor are asphalt or road oils used as fuels.

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[65] The advantages of fuel oil installations for locomotives or boats have been summarized as follows:

1. Economy of space for carrying fuel—50 percent more fuel value per unit space.
2. Ease of filling tanks.
3. Rapidity of time in meeting a varying load on boiler; fires may be instantly lighted.
4. Ability to force boiler to extreme duty in case of emergency.
5. No deterioration in storage.
6. Burns cleaner.

The disadvantages are:

1. Uncertainty of fuel supply.
2. Fluctuating price of oil.

Roy Cross, *Handbook of Petroleum, Asphalt, and Natural Gas*, Kansas City Testing Laboratory, 1931, pp. 454–455; also in Trapnell and Ilsley, *op. cit.*, p. 142.

[66] Although the demand for bunker oil fluctuates cyclically because of variations in ocean traffic, there is little indication of a shift from oil to coal during periods of high price of bunker oil. Within the last few years, ships continued to use bunker oil even though the price rose from 60 cents per barrel, in New York harbor in early 1932, to $1.30 per barrel in the middle of 1934, fell to 95 cents a barrel in the fall of 1935, rose to $1.35 a barrel in the middle of 1937, and fell to 95 cents a barrel in the fall of 1938. These prices are for grade C bunker oil for ocean-going vessels.

Source: *Minerals Yearbook, 1938*, p. 862, and *Oil and Gas Journal*, October 6, 1938, p. 113.

[67] A. J. Kraemer, U. S. Bureau of Mines, *Petroleum Investigation, 1934*, pp. 1365–1366, and Shurick, *op. cit.*, p. 517.

[68] United States Maritime Commission, *loc. cit.* These figures apply to ships of 2,000 gross tons or more. In the world, the other 12 million gross tons were for motor ships.

[69] *Petroleum Facts and Figures, 1937*, p. 33.

[70] *Ibid.*

[71] *Ibid.*, p. 32; *Minerals Yearbook, 1938*, pp. 880–81. The use of coal by railways decreased about 27 percent from 1929 to 1937 and the use of fuel oil only about 10 percent; *Mineral Resources, 1931*, p. 642, and *Minerals Yearbook, 1938*, pp. 697, 880.

[72] In the latter year residual fuel oil consumption amounted to 34.0 million barrels and light fuel oils amounted to 10.0 million barrels.

Natural Gas

For many of its uses natural gas does not compete directly with coal or water power. It has been estimated that less than half of the natural gas consumed in 1929 entered directly into competition with coal.[73] In the Southwest and in California gas is used for many requirements ordinarily supplied by coal. In many districts natural gas has been substituted for manufactured gas produced from coal or gas oil. For space heating in homes, natural gas is usually expensive, although it is comparatively economical near gas fields and in places with mild winters. In the South and Southwest natural gas is being used in this way to an increasing extent. Even in the North it is being adopted by families in higher income groups. Since 1929 the rise in the importance of natural gas for house consumption has been rapid, although figures do not indicate how much of the domestic use represents cooking and hot-water heating and how much space heating. According to statistics published in *Gas Age Record*, the number of dwellings heated with natural gas rose from 144,000 at the end of 1929 to 435,000 at the end of 1934. Natural gas, however, still remains less important than fuel oil in this field.[74] Both natural and manufactured gas have been substituted for coal for cooking and water heating. Not only is gas much more convenient, but appliances for gas tend to be cheaper than those for coal. Natural gas as supplied for domestic use usually obtains a premium price as compared with coal, but is often far cheaper than manufactured gas or electric energy.[75] Use of natural gas in homes within the past few years has continued to expand at the expense of manufactured gas. From 1933 to 1937 natural-gas consumption for domestic use rose from 283 billion cubic feet to 372 billion, and at the same time consumption of manufactured gas for domestic purposes, including house heating, fell from 242 billion to 240 billion cubic feet.[76]

A recent threat to coal appears in the projected construction of a natural-gas pipe line from the Hugoton field in Kansas through the Plains States to the Mesabi iron-mining districts in Minnesota.[77] The delivery of cheap natural gas to this district would result in a partial loss of one of coal's most profitable markets. Coal suffered severely in the rapid change from manufactured gas and coal itself to natural gas in the Chicago district; the delivery of Texas natural gas to Illinois rose from nothing in 1930 to nearly 52 billion cubic feet in 1936. As yet, natural gas has not seriously invaded the North Atlantic seaboard market; it is not delivered at all into New England.

Consumption of natural gas in generating electric power has expanded very rapidly in the past two decades, whereas the uses of both coal and fuel oil have grown but slightly. In 1937 approximately eight times as much natural gas was used in producing electric power as in 1919, whereas the consumption of coal and oil increased only 21 percent and 28 percent, respectively.[78] This great expansion in natural-gas consumption no doubt represents some substitution of this fuel for other fuels, but in the main it probably results from the use of natural gas in rapidly growing localities in and near producing fields. Of the 170 billion cubic feet of natural gas consumed by electric power plants in 1937, Texas, Louisiana, California, and Kansas accounted for approximately 60 percent.[79] Since 1919 the great increases in consumption have occurred in those States.

To some degree, natural gas has displaced kerosene both as an illuminant and as a fuel. Indeed, in the neighborhood of oil and gas fields there is considerable competition among the various refined products as sources of heat and mechanical energy.

Liquefied Petroleum Gases

Liquefied petroleum gases have been substituted for manufactured gas either directly or by mixing, although in the main these "bottled" gases constitute a supplementary source of fuel. They are being used for domestic purposes, notably in small isolated towns not served by natural-gas pipe lines. In these places "bottled" gases have been used primarily for cooking. There was a great increase in the domestic consumption of these gases during 1937, but between the years 1933 and 1936 the increase was somewhat less than that for heating oils.[80] Liquefied petroleum gases are being used in small quantities as fuel for internal-combustion engines. Dickerman has pointed out that in one instance where surplus blast-furnace gas was available, it was mixed with propane and used for industrial purposes.[81] The most important uses, accounting for nearly half of the consumption in 1937, are as industrial fuel and in the manufacture of chemicals.

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[73] Berquist and Associates, *op. cit.*, p. 26.

[74] *Final Report of the Federal Trade Commission on Utility Corporations*, 70th Cong. 1st sess., S. Doc. No. 92, pt. 84–A, pp. 50–51.

[75] Judson C. Dickerman, "Organization of the Production, Transportation, and Distribution of Natural and Manufactured Gas in the United States of America," *Third World Power Conference*, sec. 11, paper No. 6, Washington, 1936, p. 16.

[76] *Minerals Yearbook, 1938*, p. 907; U. S. Bureau of Mines, *Mineral Market Reports, No. M. M. S. 682*, December 13, 1938, p. 1; American Gas Association, *Monthly Summary of Gas Company Statistics*, Annual Supplement, March 1939, pp. 8, 10.

[77] Bituminous coal interests filed with the Federal Power Commission petitions opposing the application of the Kansas Pipe Line Gas Company for permission to build this 2,300-mile gas line, but these petitions were denied. The Commission ruled it had no power to regulate competition between various types of fuel, although it authorized the coal interests to be represented at the hearing. The gas company has applied to the Reconstruction Finance Corporation for a 2-million-dollar loan to finance the construction of the proposed line, the total cost of which is estimated at $21,470,000. *New York Times*, September 15, 1938, p. 39; also *Oil and Gas Journal*, January 26, 1939, p. 63, and March 9, 1939, p. 40.

[78] *Petroleum Facts and Figures, 1937*, p. 33; Federal Power Commission, *Electric Power Statistics, 1937*, pp. 20, 22, 24.

[79] *Ibid.*, pp. 23–24.

Natural gasoline, which is derived from natural gas, competes in some districts with gasoline produced from crude petroleum, and in areas of high production, such as the Panhandle district of Texas, natural gasoline has largely displaced regular gasoline. In the main, however, natural gasoline is a supplementary fuel.

Competition of oil and gas has led to increased efficiency in the use of coal and electric energy, and in turn the evidence indicates that the competition of other fuels has been beneficial in stimulating better utilization of petroleum and natural gas.

Increased Efficiency of Use

Efficient use of fuels can result either from the employment of a cheaper fuel in an old machine or furnace or from the development of more efficient ways of consuming the same fuel. Probably most of the gains in efficiency have resulted from the development of improved furnaces or more effective motors, although some improvements have accompanied the shift from coal to oil or gas.

Gasoline

The chemical composition of gasoline has been better adapted to motor requirements in the past few years, in particular to the variation in driving conditions from summer to winter. Moreover, the octane rating of gasoline has been increased so as to permit the effective operation of the newer types of engines. These improvements represent better performance and perhaps a more efficient use of fuel.

Yet during the past few decades there apparently has been little change in the average mileage per gallon for passenger motor vehicles.[82] On the side of efficiency there have been important gains in quality of fuel, engine construction, and highway building. These improvements have been offset by the development of heavier and more powerful automobiles which travel at higher rates of speed. Moreover, the efficient use of gasoline has been retarded by the increasing traffic congestion in large metropolitan areas and even on country highways. Considerable saving could be achieved by the general use of by-pass highways around metropolitan areas, instead of forcing the traffic through the busiest street in every town along the route, and by the provision of four-lane highways between large cities, particularly in the more thickly settled sections of the country. Further improvements in automobile construction probably will make possible additional gains in efficiency of use of motor fuel whenever the price of motor fuel rises sufficiently. It has been estimated that cars could be constructed with approximately double their present mileage per gallon whenever the people desire it or are forced by price to use such cars.[83]

Kerosene

The efficiency of using range oil has improved greatly since 1932, owing to the improvement in burners, which at first were only makeshift devices.[84] Development of better tractor engines has conserved fuel—both kerosene and lower grade oils.

Fuel Oil

The use of Diesel oil has increased rapidly in the past few years because of the introduction of Diesel motors in railroad and motor transport. Comparative tests indicate that Diesel engines in truck service get approximately twice the mileage that the gasoline engine attains.

Until recently the Diesel engines have been very selective in the type of gas oil which they could burn. The engine apparently has been greatly improved, however, and its tolerance for fuels increased.[85] On October 24, 1938, the Dodge truck division of the Chrysler Corporation announced that it was producing a three-ton Diesel truck for 1939. The corporation reported that after years of research they had corrected previous deficiencies in Diesel motors, such as knocking, smoking, and starting difficulties.[86] In November 1938, the General Motors Corporation also introduced Diesel-operated trucks for heavy use. Diesel engines are apparently still not efficient for loads lighter than three tons.

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[80] From 1936 to 1937 the domestic use of liquefied petroleum gases increased from 30 million to 40 million gallons. *Minerals Yearbook, 1938*, p. 960.

[81] *Op. cit.*, p. 19.

[82] H. C. Dickinson of the U. S. Bureau of Standards, *Petroleum Investigation, 1934*, p. 123.

[83] *Ibid.*, p. 123 and p. 577. See also H. L. Horning, *What the Automotive and Oil Industries Could Do for Each Other*, Fourth Annual Meeting of the American Petroleum Institute, 1923, p. 35; and also a paper by Mr. Horning given at the National Petroleum Association meeting in Cleveland, Ohio, April 23, 1931.

[84] U. S. Bureau of Mines, *Mineral Market Reports, No. M. M. S. 600*, p. 3.

[85] A. J. Kraemer, *op. cit.*, p. 1361.

[86] *Journal of Commerce*, October 25, 1938, p. 2.

For locomotive use, Diesel motors have proved comparatively profitable.[87] The one difficulty with these motors has been that the high-speed Diesel engine intended for conditions of sudden changes in speed and wide variations in load is very selective in its fuel supply, much more so than is the Diesel engine used in stationary service under conditions of approximately constant speed and load. As already indicated, however, the tolerance of these engines is being widened so fewer grades of fuel oil need to be produced, thus reducing refining costs. Moreover, greater efficiency has been achieved by railroad locomotives in the burning of fuel oil to heat boilers.[88]

In the Diesel engine a larger proportion of the fuel energy is transformed into useful work. Moreover, Diesel oil is a less expensive fuel, partly because it is easier to produce and partly because of the present low demand. Naturally, increased use of Diesel engines means that one petroleum product will be substituted for another, and it may mean that fuel oil, now in part a raw material for the manufacture of gasoline, will itself become the superior motor fuel.

More effective use of heating oils has resulted from the adoption of special oil furnaces in place of the makeshift burner units installed in coal furnaces and from the development of better designed oil furnaces. The difference in the cost of burning fuel oil in a special burner unit and in a conversion unit approximates 17 percent.[89] Better fuel oil burners undoubtedly have led to more efficient coal-heating equipment.

One of the major consumers of fuel oil is the petroleum refinery. Improvements in refinery design, particularly relating to the exchanging of heat, have led to greater efficiency in the use of fuel oil since 1909. In that year approximately 860 million British thermal units were required per barrel of crude run to stills. By 1936 this fuel consumption had fallen to approximately 640 million British thermal units per barrel.[90] The greatest improvement in fuel efficiency in refineries occurred between 1926 and 1929.

Great improvements in the efficient use of heavy fuel oil by railroads are expected to be made in the next few decades. In 1920 railroads required 6.8 barrels of fuel oil to develop 1,000 horsepower-hours of energy; the committee of the board of directors of the American Petroleum Institute estimated maximum efficiency in this use would be reached in 1970 with only 2.3 barrels of fuel oil required to produce the same energy. Increases in efficiency of use of fuel oil by ocean-going ships, electric plants, and industrial and domestic consumers were also forecasted.[91]

Other achievements in more effective use of fuel oil have occurred in connection with the adoption of naphthenic gas oil as a solvent for asphalt, in place of the paraffinic gas oil, and in connection with the development of a special gas oil to use as an absorbent in production of natural gasoline from natural gas.[92]

Other Refined Products

Within the past decade still gas, or refinery gas, has been recovered and used mainly as a fuel by refineries.[93] Cracking of oils, reforming of straight-run gasoline, and lowering of vapor pressure of gasoline have contributed to the production of still gas. These vapor-rich gases may be used by the chemical industry, sold as manufactured gas, or polymerized into liquid fuels.[94]

Recently, refinery engineers have developed lubricants which last much longer, but production of more powerful engines and faster driving have offset part of this advantage. As the result, since 1933 the domestic demand for lubricants has increased approximately as rapidly as the demand for gasoline.

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[87] Trapnell and Ilsley, *op. cit.*, pp. 141 142. Much of the efficiency of operation of the streamlined trains has resulted from the reduction in weight owing to the use of aluminum or alloy steels. The Burlington Zephyr, operating between Lincoln, Nebr., and Kansas City, for example, weighs 200,000 pounds, whereas the train which it replaced weighed 1,600,000 pounds. The faster schedule of the new train is also in part a result of the reduction in weight of both locomotive and cars, as well as relief from carrying large amounts of water and coal.

[88] Increased efficiency has been equally important in passenger and freight service. Thus, from 1912 to 1925 Pacific coast lines of the Southern Pacific Co. reported a decrease in the gallons of oil per thousand gross ton-mile of freight from 16.63 to 11.15 and a decrease in gallons of oil per passenger-car mile from 1.37 to 0.99. These gains in efficiency were typical for railroads operating in the Southwest and on the Pacific coast. During this period increased efficiency in the burning of oil in stationary power plants and shops operated by railroad companies was reported to be comparable with that obtained in locomotives. E. B. Swanson, *Railroad Fuel Consumption*, Circular No. 6017, U. S. Bureau of Mines, January 1927, p. 6.

[89] Goodwin, *op. cit.*, p. 59. In an estimated average season the special oil burners would consume 1,300 gallons, whereas the conversion furnace would use 1,500 gallons.

[90] National Resources Committee, *Technological Trends and National Policy*, p. 158. *Fuel Efficiency in Cement Manufacture, 1909 1935*, W. P. A. and U. S. Bureau of Mines, 1938, p. 7.

[91] To produce 1,000 horsepower-hours of energy from fuel oil the following changes were estimated: For ocean transportation, from 3.1 barrels in 1920 to a maximum efficiency of 2.7 barrels in 1960; for electric plants, from 3.4 barrels in 1920 to a maximum efficiency of 2.75 barrels in 1945; and for industrial and domestic use, from 2.48 barrels in 1920 to a maximum efficiency of 1.95 barrels in 1975. Moreover, to produce the same quantity of energy from Diesel oil, the committee estimated changes: For electric plants, from 1.2 barrels in 1920 to a maximum efficiency of 1.1 barrels in 1975; for industries, from 1.2 barrels in 1920 to a maximum efficiency of 1.15 barrels in 1975; but for ocean transportation no increase in efficiency from 1.3 barrels in 1920. Nor was any greater efficiency expected in the use of natural gas or gasoline from the 1920 consumption of 22 thousand cubic feet and 2.3 barrels in 1920. *American Petroleum Supply and Demand*, p. 215.

[92] Kraemer, *op. cit.*, p. 1364.

[93] In 1932 the U. S. Bureau of Mines reports that 40 percent of the heating value of fuels used at refineries was supplied by still gas. *Ibid.*, p. 1367.

[94] *Minerals Yearbook, 1938*, p. 934.

Natural Gas

By far the largest use of natural gas is in drilling and pipe-line activities in oil and gas fields. Since 1934 great improvements have been made in the use of natural gas in field operations. The consumption of gas increased only 17 percent between that year and 1937, whereas drilling activity, the largest element in this class of demand, increased 76 percent. Moreover, there was also rapid growth in the application of gas-generated power to other important field functions, such as repressuring in the operation of gas-compression equipment on pipe lines. More efficient use of natural gas in field operations has been achieved partly by better boiler operation and the adoption of better constructed internal-combustion engines. In addition, the general introduction of field meters in place of the old daily rate agreements for drilling engine fuel undoubtedly has lessened the waste of gas.[95] Greater heat efficiency in refineries has contributed to savings of natural gas.

An increasing percentage of natural gas has been treated for natural gasoline. This branch of the industry was on a commercial basis by 1910. The natural gasoline content must be removed before gas can be transported. Consequently, the percentage treated depends somewhat on the amount and "wetness" of gas transported. In the main, there has been a tendency to use the less desirable natural gases for industrial purposes and to reserve the sweet gases for domestic and commercial consumption. In 1929 more gas was processed than was marketed, as part of the residue was blown into the air. In 1930 the proportion treated for natural gasoline recovery reached a peak of 108 percent. As a result of conservation measures reducing wastage of residue gas, the percentage has fallen somewhat in the past few years; in 1937, 86 percent of the volume of natural gas produced was treated for gasoline, the remainder being dry gas or wet gas not transported. In recent years there has been an upward trend in the yields of natural gasoline, but these gains have probably resulted more from a decline in the relative importance of production in the Texas Panhandle, a low-yield district, and from the rise in the rank of East Texas, a high-yield district.[96]

The main handicap of natural gas as a fuel has been its restriction to use in stationary engines. Efforts are being made to adapt natural gas as a fuel for motor transport, the main problem being the difficulty of storage of the natural gas. To provide an equal fuel value a tank of natural gas would have to be larger than a tank of gasoline, the actual size depending on the pressure and composition of the natural gas.

Liquefied Petroleum Gases

The greatest improvement in the use of these liquefied gases has been in developing methods of distribution. These gases now are being delivered from East Texas to the Gulf by pipe line. Special types of cylinders have been devised for domestic users. Moreover, tank trucks are being used for the shipment of these gases to gas manufacturers and industrial and chemical plants. Until 1937 a considerable quantity of these liquefied petroleum gases had been exported, notably to France.[97]

Carbon Black

Many experiments have been aimed to devise more efficient methods of burning natural gas for the production of carbon black. As yet, however, the channel process remains the dominant process and apparently the only process capable of producing certain high-grade finely divided carbon blacks.[98] The carbon-black industry is of increasing importance in the production of rubber tires and other rubber products. These consumers accounted for 72 percent of domestic consumption in 1929 and 88 percent in 1937.[99] Although carbon black is a comparatively inefficient product of natural gas, the use of carbon black in the manufacture of automobile tires has resulted in a great saving of rubber. It has been estimated that tires made with carbon black last from 2½ to 3 times as long as tires made with the next most suitable substitute.[1]

Future Demand for Oil and Gas

Although the future demand for crude petroleum will be affected by the change in consumption of each of the petroleum products, gasoline and fuel oil are likely to continue to require the great bulk of crude output. Consequently, the discussion here is restricted to those products. The future requirements for petroleum products will be the net result of growth of consuming industries and increasing efficiency in use. Although important gains in efficiency are to be expected, they probably will not be realized fast enough to offset the gains in consumption. It is likely then that the production of crude petroleum, or at least production plus imports, will continue to rise for some time. This tendency will be modified by improvements in the refining process, whereby

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[95] *Minerals Yearbook, 1938*, p. 934.

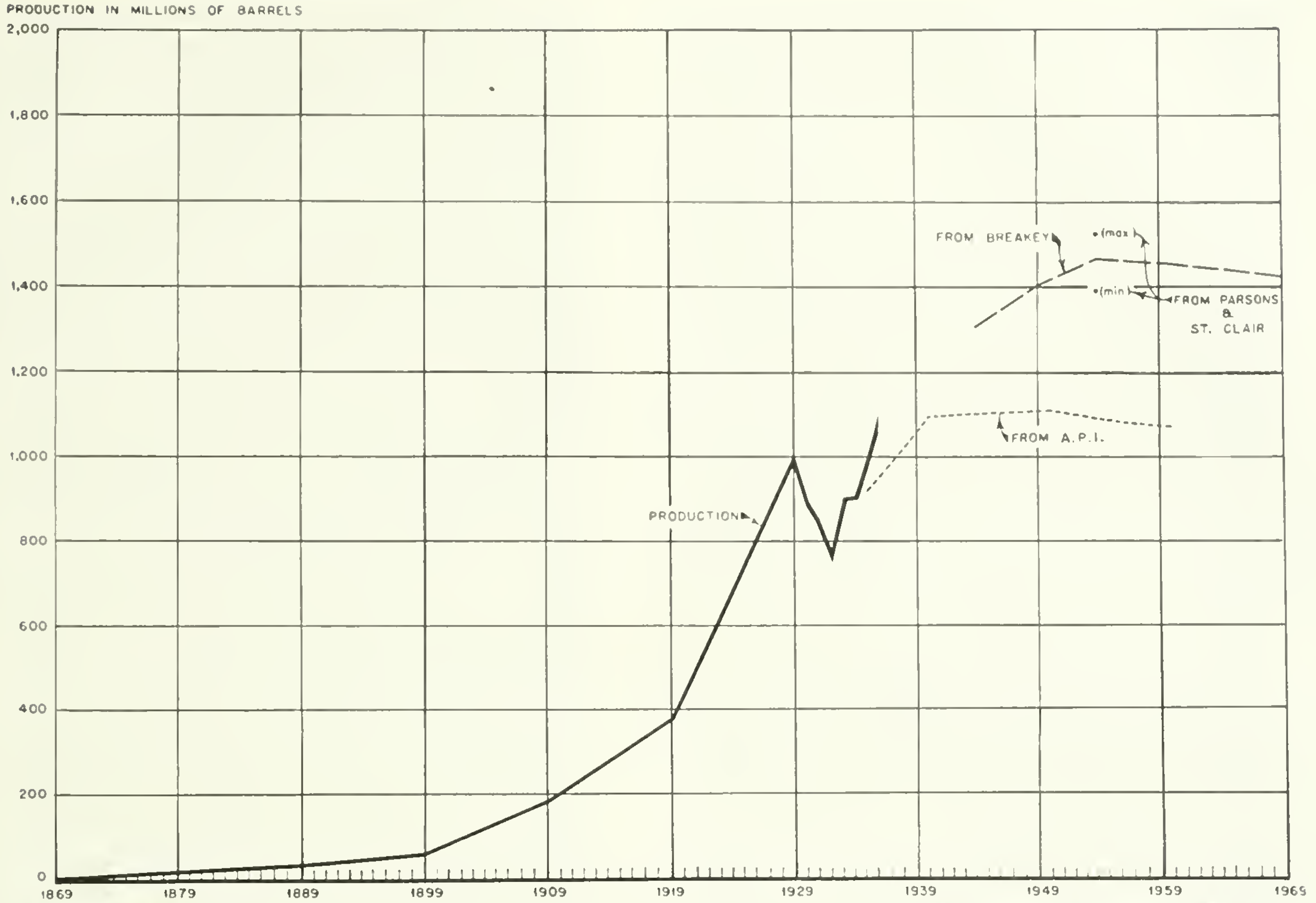
[96] *Minerals Yearbook, 1938*, pp. 908, 945.

[97] *Ibid.*, pp. 960–961.

[98] Paul Reed, "Texas Panhandle Center of Carbon Black Industry," *Oil and Gas Journal*, September 1, 1938, p. 13. Between 1935 and 1937 the production of carbon black by all other processes increased twice as rapidly as the production by the channel process. *Minerals Yearbook, 1938*, p. 964.

[99] *Ibid.*, p. 964, and *Mineral Resources, 1931*, pt. II, p. 36.

[1] John D. Gill and E. T. Knight, "What Are the Uneconomic Uses of Petroleum?" *A. I. M. M. E., Pet. Dev. Tech., 1938*, p. 286. The saving to the public in the form of longer-life tires over the past 15 years has been estimated at 40 times the value of the natural gas employed for the production of all carbon black manufactured in this country, even when valued at the average price realized for domestic consumption at the well.



Hopkins and Breakey
U. S. Bureau of Mines

Mine Mechanization and Output Per Man Studies
W. P. A.–National Research Project

FIGURE 25A.—Production of Crude Petroleum in the United States: Actual, 1869–1936; Estimated, 1935–69.

a large percentage of the more valuable products will be available for distribution to consuming industries.

Gasoline

In the past 16 years the domestic consumption of gasoline has increased 227 percent, or from 159 million barrels in 1923 to 520 million barrels in 1938.[2] This striking gain obviously has resulted mainly from the greater use of automotive transportation, which in turn has been related to the growth of population, especially to the number of families, and to a rising standard of living. Indeed, for private use the automobile has become a conventional necessity. Passenger-car registrations probably will continue to rise somewhat, although after a time the ownership of automobiles and their use may be affected by price trends for motor fuel.[3] Population of the country in 1960 has been estimated at 150 million people.[4] This estimate is 9 million less than that made by a committee of the board of directors of the American Petroleum Institute in 1925. At that time the 1960 population of the country, based largely on tabulations of the American Telephone & Telegraph Company, was set at 159 million.[5] On the basis of its recent population estimate, the American Petroleum Institute has forecast a total registration of 37 million motor vehicles in this country by 1960.[6] A continued upward trend is indicated after 1935, at the beginning of which motor-vehicle registrations totaled 25 million.

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[2] 1938 figure is preliminary, *Oil and Gas Journal*, January 26, 1939, p. 53.

[3] H. A. Breakey, U. S. Bureau of Mines, *Petroleum Investigation, 1934*, p. 91. It is pointed out that in many future years there may be occasions when the motor vehicles in use number less than those in previous years.

[4] This estimate assumes medium fertility and mortality and net immigration of 100,000 foreign-born persons annually. National Resources Committee, *Population Statistics—1. National Data*, Washington, D. C., October 1937, p. 14. Other estimates, based on varying fertility, mortality, and immigration factors are given. According to another estimate, based on American Petroleum Institute figures, population of the country in 1960 will approximate 146 million people. See *US Steel News*, October 1938, p. 4. This estimate is an average of five estimates of probable future population in this country, including the figures of the Metropolitan Life Insurance Co. and the American Telephone & Telegraph Co.

[5] American Petroleum Institute, *American Petroleum Supply and Demand*, pp. 186–189.

[6] American Petroleum Institute computation quoted in *US Steel News*, October 1938, p. 4. In 1925 the committee of the board of directors of the American Petroleum Institute reported an estimated registration in 1960 of 47 million automobiles and trucks. The drop

Consumption of motor fuel per automobile probably will continue to rise. The extent will depend in great part on the present movements toward shorter work weeks and regular annual vacations.[7] Development of better highways, constructed to avoid traffic congestion, undoubtedly will mean greater use of the automobile. From 1923 to 1937 the average domestic consumption of gasoline per motor vehicle rose from 394 gallons to 655 gallons. In only 2 years of this period did the consumption drop from the previous year.[8] Although the average consumption of gasoline per motor vehicle probably will not increase another 66 percent in the next 14 years, it appears likely that the consumption per car will continue to rise for some time. Breakey has estimated that motor fuel demand per motor vehicle will continue to rise, at least until 1950, to a figure of 22.5 barrels per car, from an estimated demand in 1933 of 17 barrels of motor fuel per car.[9]

Future gasoline consumption may be affected by a rise in the price of this fuel. To date, however, the price has fallen. From 1923 to 1937 the average retail price in 50 representative cities (excluding taxes) fell from 21.06 cents per gallon to 14.58 cents per gallon.[10] This drop in gasoline prices greatly exceeded the average drop in wholesale prices, with the result that the purchasing power of other commodities, in terms of gasoline, rose about 24 percent from 1923 to 1937.[11] What effect the rising trend in taxation has had upon gasoline sales cannot be determined.[12] It is clear, however, that if the tax per gallon were increased more rapidly than the drop in retail prices, exclusive of the tax, the resulting rise in the price might be sufficient to limit the use of automobiles.

Consumption of motor fuel by busses has increased rapidly in recent years. In 1931 consumption by these vehicles was nearly 250 percent greater than in 1925.[13] Since then the passenger bus has continued to supplant the streetcar in small- and middle-sized metropolitan communities, and from 1931 to 1937 the motor fuel demand of busses increased 35 percent. Truck consumption grew at about the same rate as passenger-car consumption until 1931, but since then consumption by trucks has increased nearly twice as rapidly as that by passenger cars; from 1931 to 1937 truck consumption increased 45 percent and passenger-car consumption 24 percent.[14] It is possible that with the development of four-lane highways with low grades both bus and truck consumption of gasoline will continue to account for a rising percentage of motor-fuel demands. On the other hand, increased pressure to put bus and truck traffic on a parity with rail traffic so far as taxes and regulation of rates are concerned may have the opposite effect.

In 1937 the consumption of gasoline in the United States amounted to 503 million barrels, or approximately 25 percent more than in 1929, the peak year in industrial activity. In 1937, R. T. Goodwin, of the Shell Union Oil Corporation, estimated that gasoline consumption would be approximately 560 million barrels in 1940.[15] In 1925 a committee of the board of directors of the American Petroleum Institute placed the 1940 consumption at no more than 403 million barrels and no less than 201 million barrels.[16] Although this committee probably overestimated 1940 motor-vehicle registration, it apparently underestimated the rise in consumption of motor fuel per car.[17] The domestic consumption of motor fuel probably will continue to rise for some time after the population of the country reaches a maximum, both because of the increase in the number of cars per unit of population and because of the increased consumption of motor fuel per motor vehicle.

Fuel Oil

Requirements for fuel oil may continue to grow for some years. Future demands will depend on the price of fuel oil in relation to its special advantages. In the event of price increases the demands for the heavier oils by railroads and electric and gas public-utility plants probably will shift to other fuels, whereas pur-

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of 10 million in the estimate is an indication of the degree to which the growth of the industry has slackened since 1925. American Petroleum Institute, *American Petroleum Supply and Demand*, p. 197.

[7] Breakey, *loc. cit.*

[8] American Petroleum Industries Committee, *Taxation Bulletin*, vol. III, No. 4, June 1938, p. 35; also presented by J. E. Pogue, "Gasoline and the Consumer," *Oil and Gas Journal*, September 22, 1938, p. 88. From 1930 to 1937 motor vehicle registrations increased 12 percent, and the indicated demand for gasoline increased 31 percent. Thus the average consumption per car rose something like 18 percent over this 7-year period.

[9] Breakey and Carmichael, *op. cit.*, p. 125.

[10] American Petroleum Industries Committee, *loc. cit.*; also Pogue, *loc. cit.*

[11] Pogue, *loc. cit.*

[12] There is some indication that a higher tax restricts consumption. For example, between the first 11 months of 1931 and the corresponding period of 1932 the drop in gasoline sales among States was closely correlated to the amount of the tax per gallon. States with a 3-cent tax witnessed a decline of only 3.6 percent in gasoline sales, whereas States with an 8-cent tax witnessed a decline of 12.3 percent in sales. H. J. Struth, "Economic Influence of the Gasoline Situation," *A. I. M. M. E., Pet. Dev. Tech., 1933*, pp. 68–69. Figures for other years, however, indicate no such close correlation between tax and sales.

[13] Breakey and Carmichael, *op. cit.*, p. 120 and chart opposite.

[14] *Ibid.*, p. 121, and *Minerals Yearbook, 1938*, p. 865.

[15] *Op. cit.*, pp. 56–59. Mr. Goodwin estimated, for 1940, a 20-percent increase over the 467 million barrels consumed in 1936.

[16] *American Petroleum Supply and Demand*, p. 202.

[17] Already, in 1931, domestic consumption of gasoline had exceeded the committee's maximum estimate for 1940. The indicated domestic demand for 1931 was 408 million barrels. Probably the committee did not anticipate the increased use of busses and trucks.

chases of Diesel oils for marine transportation, heating, trucks, and railroads are likely to persist.[18] The recent rapid growth in consumption of the lighter oils suggests that their prices will tend to rise. Increased production of distillate fuel oils requires either additional cracking of the heavier oils or the refining of a larger volume of crude. If it becomes necessary to increase crude-oil production in order to obtain a larger volume of lighter fuel oils, then these oils for the time being will be considered as the major refined product and undoubtedly will have to stand a larger share of the burden of overhead costs. Thus, a further increase in the relative importance of distillate oils is likely to lead to a rise in price.[19]

Of much importance in future demands for fuel oils are naval requirements, which in 1938 approximated 8.2 million barrels.[20] This demand is likely to increase. Moreover, the Navy is shifting some of its fuel-oil requirements from the heavier oils to Diesel oil. In some districts passenger locomotives are doing the same. Growth in Diesel-oil consumption will place a burden on the refining industry, but the additional quantities required because of a shift among petroleum products may be substantially less than the decrease in fuel-oil demands. In addition, the substitution of Diesel oil for gasoline in motor transport may lead to a relative decrease in the amount of crude runs to stills. The demand for heating oils, the important branch of distillate fuels, is also likely to expand with the rise in the standard of living, although it appears that more effective ways of consuming coal are being devised.

From 1933 to 1937 the domestic demand for all distillate fuel oils nearly doubled, increasing from 65 million barrels to 117 million barrels. Goodwin has estimated that in 1940 the sales of distillate fuels for domestic use will approximate 140 million barrels. On the whole, the demand for the lighter oils is less subject to restriction on account of price increase than is the demand for the residual oils.

Future demand for residual fuel oil depends in large measure upon price. If crude-oil production is excessive or if gasoline production rises rapidly, or, on the other hand, if Federal regulations make it possible to import large quantities of heavy petroleum crude, the price of residual fuel oil will be low enough to sustain a considerable growth in domestic consumption. The industrial demands for heavy fuel oil, which account for more than 80 percent of the total, are likely to shift easily to other sources of fuel whenever the price of heavy fuel oil rises. It has been estimated that, if the yield of gasoline is increased to 70 percent of the crude throughput at a refinery, the price of fuel oils would rise sufficiently to halve the demand for these heavy oils, but that under such circumstances the demand of the Navy and Army for these oils would remain; that a third of the present consumption by marine vessels and public utilities would be lost; and that approximately half of the consumption by railroads, oil companies, and manufacturers would shift to other fuels.[21] Neither the naval demand nor the other marine demands for heavy fuel oil are growing rapidly. Indeed, the consumption of fuel oil by vessels in foreign trade has failed to recover to the 1927–30 level of approximately 51 million barrels per year. The 1937 takings of these vessels were 36 million barrels.[22]

The committee of eleven of the board of directors of the American Petroleum Institute estimated in 1925 that the use of fuel oil by the United States Navy and the Merchant Marine in 1960 would be practically the same as that in 1925, although it indicated that until 1940 there would be a considerable upward trend in total marine consumption.[23] Under the assumption that fuel oil is retained as a major industrial fuel and with allowance for improved efficiencies, the committee estimated that by 1960 fuel-oil needs would be approximately double what they were in 1925. In other words, if land use of fuel oil is not checked by a price increase, a great increase in consumption was expected.

Natural Gas

Future consumption of natural gas probably will depend primarily upon adequacy of reserves and the degree to which they are exploited. Again, cost will be a determining factor, although considerable increases in domestic and commercial consumption cannot occur unless additional pipe lines are constructed from the gas fields. Since approximately half the natural gas is produced in association with crude oil, and since large reserves of free gas are known, a considerable upward movement in consumption can be expected in the next decade. Industrial plants will continue to account for a large percentage of consumption, although in depression years the importance of the domestic and commercial users will rise. As new products are developed from natural gas and as additional uses are discovered for old products, it may be expected that the relative importance of industrial consumption would become even greater. Moreover, it may be easier to develop new industrial uses in the field rather than to build pipe lines to distant consuming areas. In fact, most of the larger consuming areas within an economical distance of gas fields are probably already supplied with this fuel. The proportion of gas used for industrial purposes rose from 66 percent in 1911 to 81 percent in 1929, fell to 75 percent in 1932, and stood at 80 percent in 1937.

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[18] Breakey, *op. cit.*, p. 92.

[19] Goodwin, *op. cit.*, p. 60.

[20] Henry D. Ralph, "Defense Plan Will Require High Octane Gasoline," *Oil and Gas Journal*, January 19, 1939, p. 98.

[21] Breakey, *op. cit.*, p. 92. Marine demand may prove more independent of price increase than Breakey estimated. Moreover, future marine demands depend in large part on the merchant marine policy of the Federal Government.

[22] American Petroleum Institute, *Statistical Bulletin*, vol. XIX, No. 17 (March 31, 1938), Form No. 10.

[23] *American Petroleum Supply and Demand*, p. 219.

Whenever natural gas becomes scarce and its price begins to rise many industrial uses will be restricted, especially field use and the burning of natural gas in petroleum refineries and in gas and electric public-utility plants. Carbon-black demands will probably persist, and much of the domestic and commercial consumption of natural gas will remain as long as supplies are available, although in the case of commercial use it is possible to substitute other fuels, particularly in the heating of apartment buildings, hotels, and large office buildings. There is no demand which will remain irrespective of considerable price increases, except possibly that for making some carbon black, and requirements for a few metallurgical and chemical industries.

CHAPTER 5.—PROBLEMS OF WASTE AND CONSERVATION

Nature of Waste and Conservation

In producing oil from a given stratum only a certain proportion, say, 45 percent, of the total reserve can be recovered by the best known methods of operation. The remainder left in the ground does not constitute an economic waste but may be called an unavoidable loss in the sense that it represents inability with present techniques to recover the entire deposit of oil in the sand. Some operators, however, do not use the best practice and obtain a very small fraction of the total deposit, say, only 20 percent. The 25 percent which they fail to recover represents an avoidable loss or an economic waste, for this portion of the underground reservoir could have been sold for more than the extra costs of obtaining it if the best available methods were employed.

The 55 percent of the oil left in the ground by companies using the best practice might be recovered in part by mining the sands. Yet if the cost of such an operation exceeds the value of the crude obtained there is no waste or economic loss in leaving the oil in the ground; rather, there would be a waste of capital in mining it. Waste is a loss which it pays to avoid.[1] Consequently, whether a loss is a waste depends both on the efficacy of production methods and on the selling price of the oil, natural gas, or other mineral, as the case may be. What is an unavoidable loss at one time may become a waste later on if the price of the product rises relatively to the cost of obtaining the additional supplies of the product.

For a natural resource, price and, hence, the existence and extent of waste are peculiarly influenced by governmental action or lack of action. If production is restricted by proration or well-spacing regulations, crude prices probably will rise. On the other hand, if the exploitation of reserves is unregulated, prices at times will be very low, owing to the accidents of major discoveries. Severe losses of oil and gas may characterize a period of overproduction, resulting from the rapid, competitive opening up of new fields, but there is no waste from the private operator's point of view so long as price is above the cost of lifting oil. Lack of adequate regulation may have led to excessive losses of oil and gas both above and below ground. But the individual operator must view these losses largely as unavoidable;[2] in the main he has to follow field practice, no matter how bad it is. But from the social standpoint, regulation should require, or at least facilitate, the best production procedures throughout a field, and in no case should overproduction be allowed to depress prices unduly. When governmental action is taken to restrict production, the price will rise, and it will pay operators to avoid some of the losses. Thus the existence of waste depends on price. For a natural resource the Government has partial responsibility to see that the price reflects the best present and future utilization, even though consideration for the future means a higher current price.

Conservation of oil and gas may be defined as the avoidance of waste in their recovery and use. It includes the utilization of these resources with prudent and maximum effectiveness and with some consideration for future needs. Maximum effectiveness means, in technical terms, high efficiency and, in value terms, high economy. But conservation does not mean the enforced nonuse of resources so that a supply may be available in the indefinite future. There is always the possibility that the value of a resource to future generations may be less than the value of additional supplies of the resource to present consumers.

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[1] See the discussion of this problem in Myron W. Watkins, *Oil: Stabilization or Conservation*, 1938, pp. 31–36.

[2] The Federal Trade Commission has well stated that economic waste refers to a loss without equivalent gain or saving and that "physical waste of gas in connection with the oil production may, under certain circumstances, not constitute waste in an economic sense." *Utility Corporations*, 70th Cong., 1st sess., Senate Doc. 92, pt. 84–A, pp. 86–87. See also Watkins, *loc. cit.*

Various definitions of waste have been used in the oil and gas statutes of the several producing States[3] and have been the basis of extensive litigation and court proceedings.[4] The Oklahoma law, which has been sustained by the Supreme Court of the United States, lists in considerable detail the various practices which are held to be waste. Economic wastes as well as physical wastes are covered by this law. Consequently, two sections of it are presented here:[5]

> SEC. 2. The term "waste" as used in this act, as applied to the production of oil, in addition to its ordinary meaning and in addition to the meaning given thereto by any other provision of this act, shall include economic waste, underground waste, including water encroachment in the oil and/or gas bearing strata, surface waste, and waste incident to the production of oil in excess of transportation or marketing facilities, or reasonable market demands.
>
> SEC. 3. The term "waste" as applied to gas contained in or produced from a common source of supply of oil shall, in addition to its ordinary meaning, include the unreasonable production and/or the inefficient or wasteful utilization of gas in the operation of oil wells drilled therein, the escape, directly or indirectly, of gas from oil wells drilled therein into the open air in excess of the amount necessary in the efficient drilling, completion, or operation thereof; the escape, blowing, or releasing, directly or indirectly, into the open air of gas produced from wells productive of gas only, or of gas and gasoline only, drilled into any such common source of supply, save only such as is necessary in the efficient drilling and completion thereof; and the unnecessary depletion or inefficient utilization of the gas energy contained in such common source of supply. In order to prevent the waste or to reduce the dissipation of the gas energy contained in any such common source of supply, the Commission, in addition to its other powers in respect thereof, shall have authority to limit the production of gas from wells producing gas only or gas and gasoline only to a percentage of the daily open-flow capacity of such wells that is less than the percentage of oil production allowed to oil wells drilled therein.

Character and Importance of Waste

Kinds of Waste in Production

Waste of Oil at the Surface.—Although the wastes of crude petroleum at the surface have been reduced considerably in recent decades, there still remain losses in connection with well operation, treating of crude, storage, and transportation. Some difference of opinion exists as to the significance of these losses. The committee of the board of directors of the American Petroleum Institute reported in 1925 that the losses of oil under production methods then used were small.[6] Clearly, these physical losses at the surface are relatively small when compared with total production.[7] On the other hand, when translated into value terms, losses are still worth avoiding. On the assumption that all the crude oil of 24° or more A. P. I. gravity might have been stored in vapor-tight tanks from the time of production until delivery to refineries, the annual loss by evaporation was estimated in excess of $33 million in 1933.[8] At the present time the losses between the well and the refinery probably amount to 1.5 percent or more of the crude.[9]

A great improvement has occurred in methods and equipment for handling crude petroleum from the well to the refinery. In the last decade, losses from the use of open pits or open tanks as storage facilities have practically been eliminated. At one time the use of earthen tanks was common practice in new fields, and losses by seepage and heavy rains were excessive.[10] Sometimes these earthen tanks were the only facilities available to a producer lacking the use of pipe-line facilities in the field. At the present time storage facilities are reported to be more than adequate. The reduction in evaporation has resulted in a great saving of the more volatile fractions, and hence the more valuable parts, of the crude.[11] The restriction of production, of course, has led to some reduction in the recurrent peak demands for storage facilities.[12]

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[3] The oil and gas conservation statutes, annotated, 432 pp., Federal Oil Conservation Board, *Report VI to the President of the United States, 1933*. The following States specifically define waste in their statutes or set forth conditions under which oil and gas shall not be wastefully used: Arkansas, p. 33; California, pp. 59 and 80; Colorado, pp. 85, 89; Indiana, p. 116; Kansas, p. 121; Louisiana, pp. 150, 161, 168; Michigan, pp. 200, 202, 214; Mississippi, p. 223; Ohio, p. 268; Oklahoma, pp. 279, 288, 289; South Dakota, p. 317; Tennessee, p. 321; Texas, pp. 331–335; West Virginia, pp. 401–402; Wyoming, p. 412.

[4] For citations see notes in oil and gas conservation statutes, annotated, Federal Oil Conservation Board, *Report VI to the President of the United States, 1933*—California, p. 59; Colorado, pp. 85, 89; Indiana, p. 116; Oklahoma, pp. 288, 289; Texas, pp. 332–335, 358–359.

[5] See House Bill 481, Oklahoma, approved April 10, 1933. These sections are also included in Hale B. Soyster, *Review of the Petroleum Industry in the United States*, U. S. Geological Survey, Washington, April 1934, pp. 21–22. Also *Petroleum Investigation, 1934*, pp. 1227–1228.

[6] *American Petroleum Supply and Demand*, p. 82.

[7] H. C. Fowler, "Technical Developments in Petroleum and Natural-Gas Production," U. S. Bureau of Mines, *Minerals Yearbook, 1932–1933*, p. 498.

[8] This estimate assumes that the evaporated constituents represent mainly gasoline and have a value of about 5 cents per gallon. A sizable percentage of storage tanks in 1933 was still not of the vapor-tight type. *Petroleum Investigation, 1934*, p. 1245.

[9] Ludwig Schmidt of the Bureau of Mines Experimental Station at Bartlesville, Okla., estimated that these losses dropped from 6.2 percent in 1921 to approximately 1.5 percent in 1934, *Petroleum Investigation, 1934*, pp. 1916–50. On the other hand, S. F. Mauney, Jr., and G. M. Vandaveer, Jr., reported in 1938 that the figure for loss in 1934 was in excess of 2 percent, *Oil and Gas Journal*, May 26, 1938, p. 74.

[10] See the description by Wirt Franklin, president, Franklin Petroleum Company, in *Petroleum Investigation, 1934*, p. 1425. Also U. S. Bureau of Mines, *Survey of Crude Oil in Storage, 1936–1937*, Bulletin R. I. 3417, September 1938, p. 40.

[11] It has been estimated that a 5-percent evaporation of stored crude oil might result in a 70-percent loss of its original gasoline content (that is, the straight-run gasoline). On the other hand, the evaporation loss of 1934 was estimated to be not over 2 percent of the volume of stored crude, equivalent to only about 4 percent of the gasoline content, *Petroleum Investigation, 1934*, p. 742. On evaporation losses, see Ludwig Schmidt, *Applied Methods and Equipment for Reducing Evaporation Losses of Petroleum and Gasoline*, Bulletin 379, Bureau of Mines, 1934, 160 pp.; quoted in *Petroleum Investigation, 1934*, pp. 1244–1245.

[12] See testimony of W. S. Farish, chairman of the board, Standard Oil Company of New Jersey, *Petroleum Investigation, 1934*, p. 743.

Losses in pipe-line transportation of crude oil have been greatly reduced in recent years by the use of welded joints instead of the screw-type joints.[13] Pipe-line losses now are reported to occur principally in connection with air allowed to enter gravity-gathering systems and later expelled at the gathering stations with its load of rich vapors.[14]

In the past, large quantities of crude petroleum have been lost from uncontrolled wells. Although the technique for subduing these "wild" wells has improved, occasional excessive losses still occur, especially in high-pressure fields.[15] Occasionally these "wild" wells catch fire, and control is even more difficult. Fire losses are more important in connection with storage. Some of the most disastrous fires have occurred where lightning ignited the oil stored in reservoirs with wood roofs.[16] Fire losses have been estimated at about 0.5 percent of the crude produced.[17]

Waste of natural gas at the surface.—Waste has accounted for a larger proportion of the total production of natural gas than of crude petroleum. Until about 1918 the waste of natural gas in many years equaled the consumption.[18] In the Cushing field in Oklahoma the average daily waste at one time equaled 300 million cubic feet. Other notorious cases of waste occurred in the Cotton Valley oil field in Louisiana, where in 1924 billions of cubic feet of gas were blown into the air in an effort to bring oil into the wells;[19] in the Oklahoma City field in 1930, 1931, and 1932;[20] and in the Panhandle field in Texas, where in 1934 the daily waste of gas into the air amounted to over a billion cubic feet.[21] In 1937 the waste of natural gas in Texas amounted to 91.3 billion cubic feet. In California gas blown into the air at the wells amounted to approximately 16 billion cubic feet. Smaller volumes of gas were wasted in other producing States, the losses in Louisiana, and probably also Oklahoma, being only a few billion cubic feet.[22] In Wyoming in 1936 the loss of natural gas at one well, which remained out of control throughout most of the year, amounted to 16 billion cubic feet of gas, or about as much as consumption in the State.[23] In this instance, the loss was largely unavoidable.

From the beginning of the natural-gas industry until more or less effective methods of control were established in 1936, approximately 2.5 trillion cubic feet of gas were discharged in the air. In terms of heat units this enormous quantity of gas is approximately the equivalent of 3.2 million carloads of coal, which is enough coal to form a train 21,600 miles long.[24] Indeed, during the period 1922–30 it is estimated that the waste of natural gas approximated 30 percent of the total volume consumed and that the average daily waste approached 1.25 billion cubic feet.[25] The waste of natural gas continued to exceed consumption. In fact, in every year from 1923 through 1930 the volume of natural gas blown into the air exceeded the total gas consumed.[26]

In the Texas Panhandle the waste of gas has been greatly decreased in the last decade. Waste of casinghead gas was reduced from 144 billion cubic feet in 1927 to 12 billion cubic feet in 1933, while waste of gas in drilling oil and gas wells was practically eliminated.[27] On the other hand, waste of residue gas from which natural gasoline had been extracted was not materially reduced until 1935. In the first 6 months of 1934 in the Texas Panhandle alone, residue gas blown into the air amounted to 135 billion cubic feet, yet for the entire State of Texas this loss of gas amounted to only 40 billion cubic feet in 1936 and 47.7 billion cubic feet in 1937.

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[13] U. S. Bureau of Mines. "Conservation of Petroleum and Natural Gas," *Third World Power Conference*, Washington, 1936, Sec. IV, paper No. 12, pp. 9–10.

[14] Mauney and Vandaveer, *op. cit.*, p. 79. The general adoption of shut-off valves which close as soon as the flow of oil stops would practically eliminate this loss.

[15] For examples, see *Petroleum Investigation, 1934*, p. 1246. One of the most dramatic losses occurred at the Mary Sudick No. 1 well in the Oklahoma City field in March and April 1930. At the peak this well was producing a thousand barrels of oil per hour and blowing approximately a hundred million cubic feet of gas per day into the air. Much of the oil was recovered in earthen reservoirs, but the gas was lost forever.

[16] These losses applied to two fires in California in 1926 and amounted to 7,800,000 barrels of crude oil or approximately 1 percent of the total production of crude petroleum in the United States in 1926, *Petroleum Investigation, 1934*, p. 1248.

[17] This percentage applies to well and storage fires for the period 1908–17. C. P. Bowie, *Extinguishing and Preventing Oil and Gas Fires*, Bull. 170, U. S. Bureau of Mines, 1920, p. 5; also *Petroleum Investigation, 1934*, p. 1247. For the period 1915–25 the American Petroleum Institute estimated waste by storage fires at about 0.3 percent of the oil produced. No allowance was made for fire losses at the wells. American Petroleum Institute, *Report on Records of Oil Tank Fires in the United States, 1915–1925*; also *Petroleum Investigation, 1934*, p. 1247–1248.

[18] Statement of Samuel S. Wyer, of the U. S. Fuel Administration in 1918, quoted in Chester G. Gilbert and Joseph E. Pogue, *America's Power Resources*, p. 147.

[19] Report of the Federal Trade Commission, *Utility Corporations*, Washington, 1936, p. 88; and Federal Oil Conservation Board, *Report V to the President of the United States, 1932*, p. 52; Report I, 1926, p. 7.

[20] *Petroleum Investigation, 1934*, p. 1232.

[21] V. R. Garfias, "Proven Reserves of Mineral Fuels in the United States," *A. I. M. M. E., Pet. Dev. Tech., 1935*, p. 244; U. S. Bureau of Mines, *Fuels and Energy Policy*, November 1937, p. 6; and Dickerman, "Organization of the Production, Transportation, and Distribution of Natural and Manufactured Gas in the United States of America." Sec. II, Paper No. 6, *Third World Power Conference*, Washington, 1936, p. 6n.

[22] *Minerals Yearbook, 1938*, pp. 914 and 926.

[23] *Minerals Yearbook, 1938*, p. 1078.

[24] H. M. Stalcup, "What the Oil and Gas Industry Is Doing About Conservation," *Oil and Gas Journal*, May 19, 1938, p. 156.

[25] Dickerman, *op. cit.*, p. 6n.

[26] *Utility Corporations*, p. 93; also Henry A. Ley, *Geology of Natural Gas*, 1935, p. 1095.

[27] *Utility Corporations*, p. 95. The waste of natural gas in drilling oil wells was reduced from 64 billion cubic feet in 1927 to 1.2 billion cubic feet in 1933, and the waste of gas in drilling gas wells was reduced from 24 billion cubic feet in 1927 to 0.8 billion cubic feet in 1933.

The proportion of the natural gas lost at gasoline plants in the Texas Panhandle fell from 65.5 percent in 1927 to 28.4 percent in 1932. It rose again to 52.2 percent during the first half of 1934 as a result of a law permitting stripper operations. After that, markets were found for this residue gas, especially in carbon-black plants and among industrial and commercial consumers reached by pipe line. In 1937 only 4.8 percent of the residue gas was not used.[28] Another instance of the control of waste is the Kettleman Hills oil field in California. In the latter part of 1928 the entire gas output of this field was wasted. In 1930 the waste amounted to 70 percent of the total production of 158 billion cubic feet. During 1931 the production was restricted and the waste reduced 28 percent. The relative waste has been further restricted, and in 1937 in the entire State of California only 4.5 percent of the total output of natural gas was blown into the air.[29]

The great gains in conservation of natural gas are indicated by a reduction in the waste of this fuel in Texas from nearly 400 billion cubic feet in 1934 to 91 billion cubic feet in 1937.[30]

Part of the tremendous waste of natural gas was intentional. The gas was blown into the air either because of the lack of a market or in the attempt to obtain oil as soon as possible. Only within the last decade has the function of gas in raising oil been appreciated. Previously, the usual practice in a new field was to "blow it into production" by getting rid of the natural gas if the initial flow happened to be gas.[31] Other intentional wastes of natural gas have followed the extraction of natural gasoline. The natural gas has been withdrawn from the reservoir as quickly as possible in order to avoid its capture by an adjacent producer. Any use of it, even though very wasteful, was in the individual operator's point of view better than losing it entirely. Residue gas often contains as much as 97 percent of the original heating value of the gas. The wastage of this residue gas occurs only where adequate markets or marketing facilities are lacking.[32] The tremendous waste of natural gas in the Panhandle of Texas was materially restricted by the building of additional pipe lines and even somewhat by the construction of carbon-black plants.

Yet in making carbon black practically all the energy of the natural gas is lost. The effectiveness of using natural gas for this purpose has not been appreciably improved in recent years, despite research efforts to develop ways of making carbon black more efficiently than by the channel process and to make carbon black from coal. Within the last decade, however, carbon-black manufacture has shifted from Louisiana to the Texas Panhandle, thus leaving a larger share of the gas in the district nearer domestic and commercial consumers for their use.

One of the important causes of waste of natural gas arises out of the fact that a large proportion[33] of the total natural gas is produced in connection with crude oil in circumstances under which neither oil nor gas can be produced independently of the other. Consequently the quantity of gas produced is dependent primarily on the production of crude oil. In a new field the discovery of oil usually is followed by an intensive drilling campaign. Many wells are brought into production at about the same time. The demand for transportation facilities usually leads to the building of a crude-oil pipe line; but unless the field is of considerable size, no provision is made for the transportation of natural gas, and, aside from use in the field, it is often wasted. Thus the committee of the board of directors of the American Petroleum Institute looked upon the waste of natural gas as more or less inevitable.[34]

Another source of dry-gas wastage was the wide-open blowing of the wells, after they were capped, to determine periodically the capacities of the wells to produce gas. Prior to 1929, before the development of a better method, open-flow tests were permitted on wells on the public and Indian lands. A substitute method developed by the engineers of the United States Bureau of Mines has resulted in saving the wastes incident to these measurements of capacity. The "back-pressure" method of gauging capacities, it has been estimated, has resulted in the saving of millions of cubic feet of gas.[35]

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[28] Railroad Commission of Texas, *Statistics of Natural Gas Production and Consumption in Texas*, 1938.

[29] *Minerals Yearbook, 1938*, p. 914.

[30] At the end of 1934 the waste of natural gas in gasoline stripping plants in the Texas Panhandle alone amounted to 1.6 billion cubic feet per day. *Minerals Yearbook, 1935*, p. 814. Much of this waste related to the stripping of the "sour" natural gas. *Minerals Yearbook, 1934*, p. 724.

[31] Note the example of the Cotton Valley oil pool already referred to. See also *Petroleum Investigation, 1934*, p. 1248.

[32] *Utility Corporations*, p. 92.

[33] Prior to the extensive development of the Panhandle gas field it was estimated that between 60 and 70 percent of all natural gas produced in the United States was obtained in connection with oil operations. Scott Turner, *Conservation of Natural Gas in Relation to Some Recent Developments*, Bureau of Mines Information Circular 6392, 1930; also *Utility Corporations*, p. 87. More recently it has been estimated that the proportion of natural gas recovered from oil wells amounts to between 50 and 60 percent of all natural gas produced. Dickerman, *op. cit.*, p. 9.

[34] "Because of the relatively low value of the gas as compared to the oil it has not always been economical to construct the necessary pipe lines and facilities for handling the peak production of the gas which lasts for only a few months. There is a definite limit or radius within which gas can be transported and supplied economically. Gas is the most expensive of oil-field products to handle, and it has been demonstrated that gas, per heat unit, costs much more than oil. As soon as development in oil-gas fields demonstrates that there will be sufficient gas to warrant the expenditures, absorption and compression plants are constructed to handle the gas from the wells. The initial costs of such plants are large and considerable time [is] required for their construction." *Supply and Demand*, pp. 82–83.

[35] Federal Oil Conservation Board, *Report V*, pp. 53–54.

Likewise, the blowing of wells to remove accumulations of water, sand, and debris that collect in the bottom may result in considerable losses of gas to the air.[36] Considerable wastage of natural gas occurs in its transportation and distribution. Improvement in savings has resulted from the substitution of welded pipe lines for the old screw-joint pipe lines.[37] The conversion of local manufactured gas distribution systems to the delivery of natural gas often is attended by considerable waste, owing to the fact that the dry natural gas requires tighter joints.[38] Gas pipe-line leakage during recent years has been reduced by as much as 65 percent.[39]

In addition to the blowing of natural gas into the air and transportation losses, important quantities of natural gas are wasted by fires, especially at the wells. Practically every oil-well fire represents the wastage of natural gas as well as crude petroleum.

Wastes of oil and gas in the ground.—Estimates of the recovery of crude petroleum by natural methods range from 10 to 50 percent, depending upon the nature of the oil reservoir [40] and the efficiency of production. With artificial methods of pressure maintenance, repressuring, or other secondary methods, it has been estimated that in some cases as much as 70 percent of the original deposit of oil can be recovered.[41] The proportion of the oil left in the ground which can be classified as waste depends on the extent to which the most efficient methods have actually been used. Probably the variation in relative recovery from field to field depends more on the nature of the sand and other reservoir conditions than on the recovery methods, but it has been demonstrated that where the reservoir energy is wasted, only 11 percent of the potentially obtainable crude actually will be produced.[42] In the Panhandle oil reservoir it has been estimated that the wastage of gas led to the permanent loss of roughly 300 million barrels of oil. The failure to understand the importance of natural gas as a source of reservoir energy led, in the hurry to get oil, not only to the loss of the natural gas, but also to the leaving underground of a large percentage of the total reservoir supply of some of the earlier fields. Moreover, the loss of reservoir energy greatly increases the cost of recovering oil, because pumping has to be initiated sooner. Not only that, but the obtaining of the remainder of the crude requires a much longer period of time, which means more labor and a greater use of capital. Even so, from a private point of view, rapid production is often profitable. The operator may be able to get back in a few days his total investment in the well. By obtaining the cream of the deposit in a hurry, he is able to write off his investment in the well and look upon any additional income, no matter if it is spread over a long period of time, as profit, after operating expenses are paid. These methods, however, clearly will result in social waste and probably, in the long run, in a decreased operating profit. The waste of reservoir energy is sometimes intentional, particularly where competitive drilling is very intense and where the less costly methods of operation are likely to prevail; under other circumstances the waste results from a general failure to use the best engineering practice. The percentage of recovery will be reduced and the cost of obtaining some portions of the reserve greatly increased. Although intentional, such waste may often be unavoidable insofar as the action of the individual operator is concerned.

Reservoir energy is often wasted by the drilling of an excessive number of wells. The Bureau of Mines has reported that "it frequently has been impossible to work out rational spacing programs due to conditions of competitive drilling calling for a multiplicity of 'offset' wells in place of a few carefully selected wells which would have * * * prevented attendant physical losses." [43] Whether a large or small number of wells is required to produce most efficiently the oil and gas from a given stratum depends upon the nature of the underground reservoir. Only experienced engineers and geologists can space wells so that the gas-oil ratio is kept as low as possible and the reservoir energy made to recover a maximum percentage of the underground deposit. Because in most fields well spacing is decided on the basis of competitive necessity, much capital as well as large amounts of oil and gas are wasted. It has been estimated that the number of wells in the great East Texas field is two to three times what it needs to be to recover the oil most effectively.[44]

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[36] *Utility Corporations*, p. 91. "A considerable number of companies are operating wells with a siphon tubing going to the bottom of the hole in order to use the expansive force of the gas to lift water out of the well as it is produced." Thus gas is saved.

[37] The U. S. Bureau of Mines found that the leakage rate for screwed lines in good condition ranged from 250,000 to 400,000 cubic feet per year per mile of equivalent 3-inch line; for rubber-coupled lines in good condition, from 100,000 to 300,000 cubic feet; and for welded lines in good condition from 10,000 to 166,000 cubic feet. Improved methods developed by the various branches of the Federal Government were used in the construction of the 1,000-mile line from Amarillo to Chicago. Federal Oil Conservation Board, *Report V*, p. 55; see also E. L. Rawlins and L. D. Wosk, *Leakage from High-Pressure Natural-Gas Transmission Lines*, Bulletin 265, U. S. Bureau of Mines, 1928, p. 108.

[38] *Utility Corporations*, p. 92.

[39] U. S. Bureau of Mines, *Third World Power Conference*, *op. cit.*, p. 10.

[40] The quantity of oil and gas that can be obtained from a given well will be determined by the area drained, the thickness of the oil- and gas-bearing sand, the pressure under which the gas is confined, as well as the existence or absence of a water-drive.

[41] *Petroleum Investigation, 1934*, pp. 1218–1223.

[42] *Ibid.*, pp. 1220–1221. Experiments initiated by R. Van A. Mills, of the U. S. Bureau of Mines, in an effort to copy the conditions underground, show that where the gas outlet was shut in and the oil outlet allowed to produce at a slow rate the recovery amounted to 51 percent of the oil in the reservoir. The water advanced evenly without the tendency to "cone" toward the producing well, and the expansion of the free gas forced oil through the strata toward the well. Where the gas is conserved but the oil produced rapidly the recovery was only 22 percent and the water showed a decided tendency to "cone" toward the well. Where the gas is produced and wasted the recovery amounted to only 11 percent. Because the water-drive forced oil into the dry-gas area, the ultimate recovery from the reservoir was materially reduced. These conditions apply to the normal dome-shaped structure. Where there is no gas cap the difference in recovery between slow and rapid production probably would be less.

[43] H. C. Fowler, "Technical Developments in Petroleum and Natural-Gas Production," *Minerals Yearbook, 1932–1933*, p. 504.

Another source of underground waste of oil and gas is the inadequate casing and cementing of wells. As a result of faulty completion, water is allowed to enter the oil-bearing sands and to waste large amounts of oil as well as raise the gravity of what oil is produced, owing to the formation of emulsions which have to be treated with resultant evaporation.[45] The harmful infiltration of water has been considered the greatest source of waste of crude oil by some authorities.[46] Faulty completion of wells also results in the escape of gas from purely gas-producing strata into other strata or to the surface. Gas lost to oil-bearing strata may help lift oil to the surface but is, in the main, wasted. The use of dry gas from other formations to lift oil results in the production of gas that need not have been produced at all with the oil recovered. The underground losses of oil and gas through faulty well completion are less prevalent now than in the 1920's.[47]

Waste of capital.—The building up of a larger productive mechanism than is necessary leads to the investment of excessive funds in the oil and gas industry. Imperfect State restriction on production from new oil and gas fields has meant that an excessive number of wells have been drilled especially in and near areas of flush production. Governmental agencies, particularly geological bureaus, have given some assistance to drilling companies in divining where oil and gas are most likely to be discovered. There is, however, no effective Government restriction of exploratory activity to the current needs for new supplies of oil and gas. The most important source of capital waste lies in the drilling of unnecessary wells. It has been estimated that in the East Texas field alone 12,500 more wells were drilled than were needed to produce the oil and gas. At an average of $13,000 per well, the capital waste in drilling in that field amounted to $162,000,000.[48]

The excess cost of obtaining oil under such conditions leads either to bankruptcy of operators or rising prices of oil. In the Oklahoma City field the practice of offset drilling resulted in the failure of most small operators and in heavy losses to many large concerns.

Overproduction of crude oil during the period of poor business conditions in the late twenties and early thirties gave rise to the construction of extensive storage facilities, although speculation during the twenties also led to a great rise in storage capacity. Subsequent restriction of production finds the industry with a large excessive investment in storage facilities. On June 30, 1936, empty storage capacity for crude petroleum was estimated at 260 million barrels out of a total capacity of 583 million barrels.[49] Great capital wastes have occurred because of the rapid development of oil fields. If these fields had been developed at a slower rate and production had been at a lower level, the investment in pipe lines, for example, might have been materially restricted.

Causes and Significance of Wastes in Production

Legal system of land and subsoil ownership.—One of the major causes of waste of oil and gas relates to the right of the individual landowner to "capture" all of the oil and gas which is produced from wells on his property. The migratory nature of oil, when the static-pressure balance in the pool is disturbed by drilling, leads to a movement of oil in the direction of reduced pressure. Consequently a well can and often does drain reserves from adjacent property. In many fields, the adjacent landowner has no effective way of protecting his subsoil mineral rights other than to drill offsetting wells as rapidly as possible. In the effort to recover the maximum of oil in the minimum of time, a large proportion of the reservoir energy may be wasted. Competitive methods based on the "law of capture" still characterize a large part of the industry. Moreover, the speed with which new fields are brought into flush production makes it unlikely that adequate marketing facilities will be available for the accompanying natural gas until after large quantities of this fuel are blown into the air. The speed of production may be the major cause of underground losses of both oil and natural gas.[50] The alternative to competitive production is some kind of a system of unit-field operation in which the spacing of wells and the rate of operation are based upon efforts to recover a maximum proportion of the underground resources and to make most effective use of the lifting power of natural gas.[51] Moreover, production would be held back until adequate marketing facilities were provided.[52]

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[44] *Petroleum Investigation, 1934*, pp. 2162-2163. See also the discussion of this problem by James A. Veasey, general counsel of the Carter Oil Co., a subsidiary of Standard Oil Company of New Jersey, *ibid.*, p. 1708.

[45] Mauney and Vandaveer, *loc. cit.* "The condition and type of flowing and pumping equipment has a considerable effect on the type and amount of emulsion formed. * * * Repair of leaky pumps and removal of constrictions that cause extreme agitation can prevent or decrease formation of emulsions."

[46] Gilbert and Pogue, *op. cit.*, p. 108.

[47] *Utility Corporations*, pp. 89-90.

[48] William E. Hubbard, "Economics and Well Spacing in Texas," *A. I. M. M. E., Pet. Dev. Tech., 1937*, p. 170. The cost of excessive drilling also is indicated by the operation of the so-called Golden Lane field in Mexico. The competitive part of that field is reported to have produced oil at a cost of 19.3 cents per barrel in comparison with the cost in the noncompetitive part of the field of 5.9 cents per barrel. E. L. Estabrook, "Unit Operation in Foreign Fields," *A. I. M. M. E., Pet. Dev. Tech., 1931*, p. 44.

[49] U. S. Bureau of Mines, *Survey of Crude Oil in Storage, 1936–1937*, Bulletin R. I. 3417, September 1938, p. 35.

[50] Federal Oil Conservation Board, *Report V to the President of the United States, 1932*, p. 52; *Utility Corporations*, p. 89; Garfias, *A. I. M. M. E., Pet. Dev. Tech., 1935*, p. 244.

Small landholdings.—The wastes resulting from the operation of the "right to capture" are accentuated in many fields by the smallness of individual landholdings. In suburban districts or even within incorporated communities the intensive efforts to recover oil have led to wells being drilled within a hundred feet of each other. Under such circumstances waste is excessive. One of the first successful efforts to restrict excessive drilling relates to such a situation.[53]

Abundance of easily accessible resources.—Waste in production may result from the fact that oil and gas fields have been discovered in a large number of States and that possible oil-bearing territory is still very great. In the search for oil and gas the most easily accessible and richest deposits are likely to be removed first. Such practices lead not only to the removal of some of the best grades of crude oil as soon as discovered but also to the use of less costly equipment. The largeness of reserves of oil and gas leads to an emphasis on saving capital rather than the resource. These considerations apply particularly to the coastal oil fields, where the crude is the more valuable because of the nearness of the wells to water terminals, and also to the Texas Panhandle and Hugoton natural gas fields, where the extent of proven reserves makes it a fairly simple matter to obtain additional supplies of natural gas. In these gas fields, however, the spacing of wells, in some parts of the fields at least, have been restricted to one to every 640 acres.

Overproduction and depressed prices.—The abundance of possible oil-bearing strata and the inadequate restriction of drilling efforts lead to serious overproduction if a major oil field happens to be discovered in a period of business recession. Such a situation occurred in the Seminole field in Oklahoma in 1927 and in the East Texas field in 1931. The rush to drill wells in a field would be just as great in a period of depression as in a period of prosperity once the field had been opened up. Changes in market demand may have some controlling effect over production in older fields, but very little effect in newly discovered fields during flush production periods. If drilling operations and production are not restricted somewhat in relationship to the changes in demand, prices of oil and gas are likely to fall, and efforts to conserve supplies of oil and gas are likely to be dropped. Producers have no time to save gas when there is a race between adjacent leaseholders to acquire a greater proportion of the more valuable crude oil, nor are efforts to conserve or use residue gas successful if there is competition among producers to withdraw the natural gas from a field and produce natural gasoline from it. The possibility of obtaining part of the resource under another's property promises a greater reward than efforts to conserve the oil and gas already obtained. Depressed prices may be accompanied not only by the loss of less valuable parts of the crude oil but also by the failure to use more efficient productive equipment. Moreover, in a new field the price is further depressed by the fact that the available market is likely to be a local one and that the chance of obtaining an outlet for the oil and gas will depend upon proof that the new field is of sufficient size to warrant the construction of pipe-line facilities. For example, domestic and industrial consumers of natural gas in a distant metropolitan area are not going to agree to change from manufactured to natural gas unless they are assured that the supply of the latter will be sufficient to last a number of years. Witness the caution of the Denver distributing utility in agreeing to purchase natural gas from the Amarillo field.

Whenever the production of crude oil is far in excess of market demands, large quantities of oil must be stored in wait for improved business conditions or transferred to more distant markets. In both cases there are likely to be some storage losses. Moreover, the extra investment in these facilities in a sense is unjustifiable. At times crude oil must be stored for a period of several years. The cost of storing per year may in a depression year amount to as much as the original value of the crude.[54] In addition, the loss of interest on investment in the crude itself is also considerable.

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[51] An extreme example of the effect of reduction of gas pressure in a producing oil field has been described by George W. Stocking as follows: "In March 1920 the discovery well was completed in the Stephens County, Okla., oil field. This well was located on a 160-acre farm. The initial production was approximately 750 barrels. With the completion of 7 additional wells the lease production increased to 6,000 barrels, after which it began to decline. In the meantime an active-drilling campaign had begun in adjoining tracts. Two wells at a distance of about a quarter of a mile 'came in' unexpectedly about June 1 as gas wells. The total production on the above tract at this time was approximately 4,700 barrels. With the completion of the gas wells, which 'ran wild' for several weeks, the oil production on the 160-acre tract dropped 500 barrels 1 night and rapidly declined thereafter. Despite the completion of 4 additional wells the production on July 1, 4 weeks later, was down to 2,300 barrels. Meanwhile, several other gas wells were completed, 1 being an offset to a 300-barrel oil producer on the 160-acre farm. This well dropped to 200 barrels with the completion of the gasser. Before the latter well had been shut in, all the oil wells on the adjoining property had ceased to flow naturally and it was necessary to place them on the pump."

Stocking, *The Oil Industry and the Competitive System,* 1925, pp. 171 173; also *Utility Corporations,* pp. 88–89.

[52] The major reason for unit operation lies in avoiding underground waste. In the Texas Panhandle oil district it has been estimated that the competitive development of the field and the wastage of gas from the reservoir have resulted in the loss of from 400 to 500 million barrels of recoverable oil. See statement by J. G. Dickinson, Superintendent of production, Texoma Natural Gas Co., Emerald, Tex., *Petroleum Investigation, 1934,* p. 1240; on the disadvantage of producing oil at too slow a rate, see p. 2136.

[53] In 1928 the city of Oxford, Kans., was upheld in its efforts to limit the drilling of wells to one per city block. *Marrs.* v. *City of Oxford,* 24 F. (2d) 541 (D. Kan. 1928), aff'd, 32 F. (2d) 134 (C. C. A. 8th, 1929), cert. denied, 280 U. S. 573, 563 (1929); discussed by Northcutt Ely, "The Conservation of Oil," 51, *Harvard Law Review,* 1235.

During periods of overproduction marginal wells are likely to be shut down; and, if the price of oil threatens to remain low for some time, the wells may be abandoned and the equipment moved to more profitable areas. This practice results in substantial hidden loss in ultimate recovery from these abandoned wells; for, if prices had been somewhat higher, it might have paid to continue their operation or even to install improved equipment. Once oil wells are plugged, it may be impossible to open them up again after prices rise above their costs of operation.[55] The abandonment of wells because of low price of crude has been estimated to constitute a considerable economic loss.[56]

Special marketing difficulties.—Under circumstances of flush production or even of production from old fields during a period of business depression, some oil producers have been refused access to pipe-line facilities.[57] The operator may be forced to store his crude temporarily in earthen reservoirs or to ship it by tank truck or railroad. Considerable waste in handling is likely to result. As already indicated, the discovery of a new gas field may lead to an immediate oversupply of local tributary markets. As suggested, natural gas distributing companies in other districts may be unwilling to tie up with pipe lines leading from the new field, particularly where natural gas is being produced as a byproduct of oil, until assured that the supplies of gas are adequate. In the meantime there probably will be considerable waste. The same considerations apply to the construction of crude pipe lines by distant refiners.[58] Where a distributing company or affiliated group has a monopoly of pipe-line facilities in producing territory, some owners of natural gas wells may at times be unable to sell their supplies and thus be forced to let the gas go to waste in the air.[59]

Another difficulty in marketing natural gas may lead to considerable waste. Since the maximum demand for oil occurs in the summer and that for gas in the winter, it is difficult to dispose of all of the natural gas during the summer in those fields where gas and oil are produced together. Waste is sometimes reduced by returning the excess natural gas to its natural reservoir. In some instances, production of oil in the winter in excess of market demands has been resorted to, but this results in extra storage and some waste of crude petroleum.[60]

Distance from market and low prices at well.—The waste of oil and gas may be accentuated in those fields discovered far from centers of population. Prices are low because of the great transportation costs and perhaps also because of the flush production of oil and gas. In such distant fields pipe-line facilities may not be constructed until after a considerable delay. Consequently, there is always a great waste of quantities of natural gas.

Inefficient methods.—Probably in every oil and gas field in the country wastes result because of the use of inefficient methods and out-of-date equipment. The explanation may be related to the low price of oil and gas, to ignorance of the best geological and engineering advice, or to lack of capital, and hence inability to take a long view. The advantage of a new method is very difficult to establish in the oil industry because of the uncertainty about what occurs in the reservoir. Only after considerable experimentation is a change made to the more up-to-date procedure. Thus, only within the last decade or so has the function of reservoir energy been fully appreciated, although experiments in some kind of control of the gas-oil ratio were made years before. Moreover, the adoption of newer techniques may be delayed by the difficulty of managing a dispersed enterprise with producing wells in many districts. During a period of flush production many operators apparently feel that more is to be gained by speeding up production than by a careful check of operating methods and equipment to see that only the best practice prevails.

Regulatory difficulties.—Some waste probably results from the delays in applying uniform rules by State regulatory bodies to all parts of an oil field. More wastes may result from applying blanket regulations to different fields or all parts of the same field without adequate knowledge of reservoir and other production conditions.[61]

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[54] On storage problems, see Wilbur F. Cloud, *Petroleum Production*, 1937, Chapter XVI, p. 554.

[55] Well casings corrode, in some areas at least, three times as fast in shut-down wells as in producing wells. Severe corrosion may cause the casings to collapse. Under such circumstances redrilling or repairing the well is necessary before it can again be pumped. Such an extra expenditure may not be justified even with a considerable rise in price. Furthermore, premature abandonment of wells may involve seepage of surface and underground waters into oil-bearing strata and the loss of the reserve. It may be desirable for the State to require conditioning of wells before they are temporarily shut down. U. S. Bureau of Mines, *Third World Power Conference, op. cit.*, pp. 6–7.

[56] Statement of H. F. Sinclair, *Petroleum Investigation, 1934*, p. 2507. In addition, see the data presented by Katharine Carman of the Petroleum Administration Board, *ibid.*, pp. 398–429.

[57] Statement of Joseph Danciger, *Petroleum Investigation, 1934*, pp. 2200–2201.

[58] E. DeGolyer, "Organization of Production, Refining, and Distribution of Petroleum and Petroleum Products," *Third World Power Conference*, Section II, Paper No. 5, pp. 4–5.

[59] In the recent suit filed against the Columbia Gas and Electric Company for violation of the Sherman Antitrust Act, it has been alleged that the corporation has dealt unfairly with producers of gas and owners of gas reserves in the Kentucky and West Virginia fields. *Journal of Commerce*, November 5, 1938, pp. 1 and 5.

[60] Federal Oil Conservation Board, *Report V*, pp. 52–53; Federal Trade Commission, *Utility Corporations*, p. 90.

[61] The question of how to regulate production from combination wells, which produce both gas and high-grade distillate, has a vital bearing on the problem of waste and its prevention. If these wells are produced as oil wells, the gas may be allowed to be wasted. *Oil and Gas Journal*, May 19, 1938, p. 38.

Causes and Significance of Wastes in Use

Inefficient consuming equipment.—Oil and gas are as effectively wasted in consumption if only partly used as in production if only partly recovered. At one time petroleum refineries and chemical plants were not adequately equipped to save all parts of the oil or gas which they were processing. An important present cause of waste of natural gas lies in the continued use of equipment of poor design. Considerable wastage of gas may occur through inefficient combustion or inefficient application of heat. Waste due to the use of old-type stoves may still be considerable. Moreover, distribution facilities may not be of the most modern type and may be losing important quantities of natural gas. Waste of this kind can be avoided only by additional capital expenditures on new equipment. The possibilities of savings may not be sufficient to warrant the extra investment. Expenditure and in some instances the waste may be incurred by a person other than the owner of the equipment—incurred by a renter, for example. Similar losses occur in connection with the burning of kerosene and fuel oil whenever the equipment is not adequately designed to provide effective combustion and application of heat. Losses of this type, although of considerable magnitude, are far less important than losses occurring in the production of oil and gas.[62] Waste of fuel in motors may result from the use of inefficient equipment. In the main, this problem has been treated in chapter IV. It may be pointed out here, however, that further savings of motor fuel will mean development of smaller automobiles,[63] further streamlining, the use of multiple gear shifts, overdrives, or freewheeling, less vapor loss,[64] more complete combustion, and perhaps eventually the substitution of the more efficient Diesel motor.

The fullest use of distinctive qualities.—In burning oil and gas products, efficient utilization would require that a more valuable product be retained for uses where advantages could be made of its more unusual characteristics. Thus, it is ineffective use, if not waste, to burn sweet gas in manufacturing carbon black, when adequate supplies of sour gas are available. Sweet gas should be reserved for domestic and commercial use, because sour gas is corrosive to equipment and dirties the burners.[65] Moreover, any sweet gas containing commercially recoverable helium should be retained for the production of that gas rather than used immediately for fuel. Propanes and butanes must be removed from natural gas before being sold to distributing companies. The saving of these valuable liquefiable gases actually improves the quality of natural gas for domestic and commercial use because too much butane introduced into gas lines causes condensation, water hammer, and the formation of hydrocarbon hydrates.[66] Thus prudent utilization requires that the most valuable parts of oil and gas be removed and not be consumed incidentally with less valuable fractions.

Problem of less urgent use.—If all of the crude oil could be used to manufacture the more valuable petroleum products and the users of the less valuable products be shifted to coal, the production of crude oil might be materially restricted and the life of reserves correspondingly increased. This suggestion was made by the Federal Oil Conservation Board in its first report in February 1926.[67] In the main, it was based upon the realization that reserves of natural gas and petroleum are much smaller than those of coal and that the functions of heavy fuel oils may be performed by coal. In present refining processes the production of motor fuel by cracking petroleum fractions as light as gas-oil and even kerosene results in the production of some heavy oil.[68] Some oil producers have favored the restriction of fuel oil use wherever coal is available and suitable. C. B. Ames, chairman of the board of the Texas Corporation, has stated that it is undesirable for oil to displace coal where coal can be used conveniently.[69] Wallace E. Pratt, vice president of Humble Oil and Refining Company, has pointed out that there are less efficient uses of oil which might well be prohibited.[70]

It is difficult to define accurately an inferior or less urgent use of oil and gas. Perhaps a good indication is given by the price of the product in comparison with the price of crude petroleum or, in the case of natural gas, the prices of natural gas for different uses. For example, the price of heavy fuel has remained below the price of crude since 1920.[71] Whenever a product sells for less than the material from which it is made, one safely can conclude that it is a byproduct and that its use is less urgent in comparison with those of the more valuable products. With respect to natural gas, it is clearly more effective utilization to expand domestic and commercial uses and restrict industrial uses. In 1937, for example, the domestic and commercial users paid over six times more, on the average, for natural gas than did the industrial users.[72] Although part of this difference results from differences in distribution costs, the main cause is willingness of domestic and commercial users to pay more. It might be better use of gas reserves to restrict production to those uses which can pay higher prices. Very likely many of the industries would continue to use natural gas even at a marked increase in price. The social values of a product are not necessarily indicated by price. For example, the use of heavy fuel oil by passenger ships and by the Navy probably would continue even under price increases, and carbon black would probably still be produced, in the main, from natural gas at double the present cost.

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[62] *Utility Corporations*, p. 92.

[63] It has been suggested that efficiency in use and conservation would be furthered if consumption were restricted to lighter automobiles. *Petroleum Investigation, 1934*, pp. 364, 2178. It was suggested that a Packard automobile consumes approximately twice as much gasoline as a Chevrolet for a given mileage.

[64] It has been estimated that from 1 to 5 percent of motor fuel is wasted by vapor losses. T. W. Legatski and R. R. Couch, "Fuel Systems of 1937 Automobiles," *Oil and Gas Journal*, November 18, 1937, p. 53.

[65] In addition, if the stove is not connected to a flue the products of combustion of sour gas give off an offensive odor.

[66] A. E. Sweeney, Jr., "Application of Liquefied Natural Gas to Oil Development and Production," *Oil and Gas Journal*, December 16, 1937, pp. 44, 46.

[67] "Not even half of our present production of crude oil is required to supply our national petroleum demands for recognized superior uses. * * * The products thrown into inferior uses contain at least 50 percent of an easily obtained gasoline and other superior derivatives." Federal Oil Conservation Board, *Report I to the President of the United States*, p. 153.

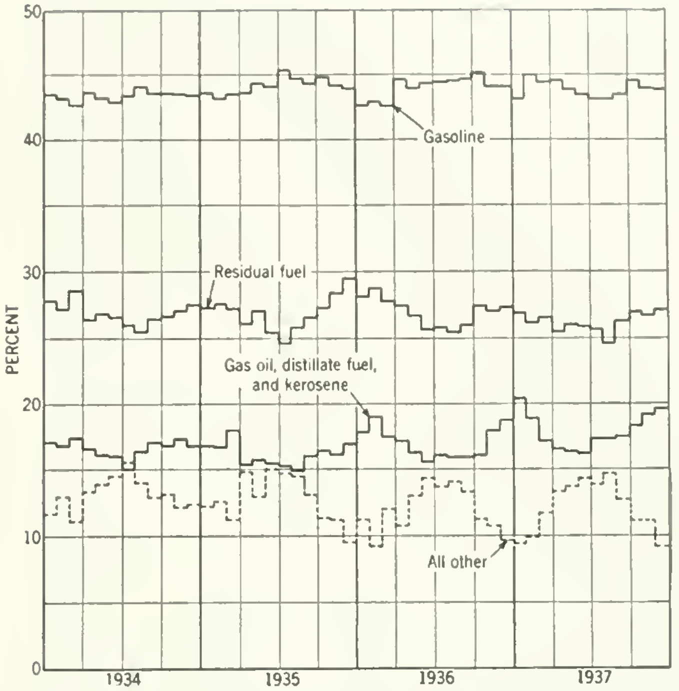
[68] Of the 310 million barrels of viscous fuel oil produced in 1937, probably upwards of 150 million barrels are estimated to have resulted from the cracking of light oils in the manufacture of gasoline. Altogether, in 1937, 533 million barrels of stock were run through cracking stills. John D. Gill and E. T. Knight, "What Are the Uneconomic Uses of Petroleum," *A. I. M. M. E., Pet. Dev. Tech., 1938*, pp. 282–284.

[69] *Petroleum Investigation, 1934*, pp. 362, 363.

[70] *Op. cit.*, pp. 2176–2179. Mr. Pratt points out that he disapproves of transporting oil into water-power districts where electric power is generated from water power at reasonable cost.

On the other hand, it may not be desirable to force refineries to increase very much the yield of gasoline from crude. Investments in cracking plants would rise, and the price of gasoline also might increase. Moreover, it is possible that the Diesel motor will be perfected and make unnecessary much of the investment in cracking equipment. A more intelligent effort might be to subsidize the development of the Diesel motor rather than to require a higher percentage output of gasoline.

The problem of restricting less urgent uses may be stated in terms of the desirability of using coal for the cheaper requirements and therefore of restricting fuel-oil sales. As a result, the price of gasoline and lighter oils might be increased. Limitation of fuel-oil sales means the restriction of present use and the saving of crude reserves for future use. Oil producers argue that this is undesirable because there are no "uneconomic" uses of petroleum,[73] and that true conservation would permit the usage of resources in accordance with the best information of the time.



U. S. Bureau of Mines
Minerals Yearbook, 1938

FIGURE 26.—Yields of Principal Petroleum Products from Crude Oil Run to Stills, 1934–37, by Months.

In the refining process there is already a considerable latitude in the relative amounts of gasoline, kerosene, fuel oil, and other products which may be produced. For example, in representative refineries on the Texas Gulf coast the gasoline fraction varies from 40 to 62 percent, the kerosene fraction from 0 to 18 percent and the lighter fuel oils from 2 to 30 percent.[74] The actual percentages of each product produced depend on the relative demands for these products at different times of the year, as reflected in their net prices at the refineries. Over the past few years the trend in the yields of the group comprising gas, oil, other distillate fuels, and kerosene has been definitely upward. There also has been a slight upward trend in the yields of gasoline. On the other hand, the relative amounts of residual fuel and all other petroleum products have been downward (fig. 26).[75] These trends do not indicate what might be done in restricting production to the so-called superior products (chapter 4). They only indicate what the recent practice has been. In some years the yield of gasoline probably has been restricted by the strong demand for heating oil.[76] These oils, however, apparently pay their own way, although the bulk of refinery income is still from gasoline sales. The seasonal peak demands for gasoline and heating oils roughly complement one another and, at least in winter seasons, heating oils may be considered in some respects as a superior use of crude.[77] Technical changes in the refinery division of the industry are in the direction of increased control over the relative amounts of individual petroleum products which may be produced. The Houdry process, developed by the Sun Oil Company and the Socony Vacuum Company, permits wider variations in production as well as more effective control.[78]

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[71] In prosperity years average residual fuel-oil prices have been a little more than half the price of crude petroleum from which they were produced. In 1933, however, fuel oil prices rose to about 75 percent of the price of crude. *Statistical Abstract of the United States, 1937*, p. 732, table 764. The prices in this table are weighted average prices compiled by Joseph E. Pogue.

[72] *Minerals Yearbook, 1938*, p. 908.

[73] "The resource is being employed as effectively as society bulwarked by a highly developed technology can feasibly employ it," Gill and Knight, *op. cit.*, p. 285. Mr. J. Howard Pew, president of the Sun Oil Company, implies that it is no more an inferior use to burn fuel oil under a boiler than it is for people to use gasoline in joy riding. He also denies that there are inferior uses for petroleum. *Petroleum Investigation, 1934*, p. 383. Mr. W. S. Farish, chairman of the board (now president) of Standard Oil Company of New Jersey, stated in 1934 that although the most essential uses of oil were gasoline and lubricants and that it might be said that any other employment was inferior use, nevertheless there were no inferior uses in the sense that they should be prohibited; *ibid.*, p. 674.

[74] George Weber, "Heating Oil Demands Widen the Range of Modern Cracking Operations," *Oil and Gas Journal*, August 4, 1938, pp. 48, 50.

[75] *Minerals Yearbook, 1938*, p. 858.

[76] *Minerals Yearbook, 1937*, p. 1024.

Effects of Waste

Insofar as oil and gas are wasted in production or in use, the life of reserves is decreased. At the present time, waste is relatively less important for natural gas than for crude oil. The waste of these mineral resources means that the period of price increases will arrive sooner. Price increases may not appear for several years, but when they do, they probably will come rapidly. Prices will remain low as long as the industry is operated on a basis of flush production of new fields, even though modified by proration. Moreover, the continued wastes of oil and gas appear certain to increase the experiments with substitute fuels. As soon as the price margin between oil and gas products and substitutes is narrowed sufficiently, demands are likely to appear for the mixing, for example, of gasoline with its substitutes. This would be an expensive process and perhaps wasteful. One of the most direct effects of waste has been the loss of employment in oil- and gas-producing districts. It has been estimated, for example, that losses of gas in the Drumright field, Oklahoma, would have maintained a considerable industrial activity in that district and would have made possible the more orderly operation of well production, so that after a period of 5 years a considerable percentage of the people would not have had to move to other oil-producing territory.[79] Where oil and gas resources are rapidly wasted, local citizens lose both their means of livelihood and a large share of their investments in properties. Moreover, the oil-producing States lose valuable sources of revenue.

If oil and gas are not reserved for their more prudent uses, domestic and commercial consumers may soon suffer both rising prices and greater inconvenience. Substitutes which are likely to be developed may be less effective, and favorably located cities which could have been heated with clean natural gas may have to return to the use of less desirable coal.[80]

Trend of Conservation Practices

Major Achievements in Conservation

With respect to petroleum, the major gains in conservation in recent years have resulted from a greater recovery of underground reserves by the use of more efficient methods and equipment and the production of a larger percentage of the more valuable refined products from the crude. With respect to natural gas, conservation has been effected by the construction of transportation facilities to marketing areas or by the return of unmarketable quantities of gas to the underground reservoir.

Within the last two or three decades the relative recovery of crude oil has been greatly increased and perhaps, on the average, has doubled. It has been estimated that, whereas in 1917 the recovery in Pennsylvania fields amounted to only 10 to 20 percent of the underground oil,[81] the present recovery by natural production amounts to roughly 20 percent, and that an additional fifth of the reserve can be obtained by repressuring methods.[82] For the United States it has been estimated that operating practices until about 1925 led to the recovery of only 10 to 20 percent of the original oil from the reservoir sands.[83] On the other hand, operating methods in 1934 were estimated to recover from 20 to 35 percent of the oil, depending largely upon the permeability of the sand.[84] Moreover, it was estimated that, by general adoption of most efficient methods existing about that time, recovery would vary from 30 to 60 percent.[85] Secondary recovery methods, such as water flooding and gas injection, can lead to the recovery of another 30 to 60 percent of the oil originally in the reservoir sands.[86] Some engineers estimate that recovery from a given pool has been increased from 20 percent to possibly 80 percent.[87] Even without a consideration of secondary methods, the relative recovery of crude oil has apparently roughly doubled. If the methods of crude production had not improved in the last few decades, the obtaining of the 1¼ billion barrels of crude petroleum in 1937 would have required that the recoverable proportion of the proven reserve be exhausted twice as rapidly or, on the other hand, that operations be carried out on twice as large a proven reserve. Thus the improvement in recovery methods has led to conservation of the crude-oil reserves, which gain in 1937 alone was more than a billion barrels.

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[77] Weber, *loc. cit.*

[78] *Journal of Commerce*, October 21, 1938, p. 17; *Fortune*, February 1939, pp. 56 and 127; Eugene Houdry, Wilbur F. Burt, A. E. Pew, Jr., W. A. Peters, Jr., "The Houdy Process," *Oil and Gas Journal*, November 24, 1938, p. 40.

[79] Earl Oliver, "Present Methods Encourage Waste," *Oil and Gas Journal*, December 17, 1931, p. 21.

[80] *Ibid.* For a discussion of the diversified groups which have interest in the conserving of oil, see R. A. Cattell and H. C. Fowler, "Influence of Petroleum Technology upon Composite Interest in Oil," *Minerals Yearbook, 1935*, pp. 771–94.

[81] J. O. Lewis, *Methods for Increasing the Recovery from Oil Sands*, Bulletin 148, U. S. Bureau of Mines, 1917, p. 8; quoted by H. C. Miller and Ben E. Lindsly, *Petroleum Investigation, 1934*, p. 1218.

[82] Testimony of George H. Ashley, State Geologist of Pennsylvania, *Petroleum Investigation, 1934*, pp. 593–598.

[83] Statement of Harold C. Miller, Senior Petroleum Engineer, U. S. Bureau of Mines, San Francisco, *Petroleum Investigation, 1934*, p. 39.

[84] *Ibid.*; on the other hand, Hale B. Soyster, of the U. S. Geological Survey, estimated that recovery in 1934 varied between 25 and 35 percent, *Petroleum Investigation, 1934*, p. 17, and Lester C. Uren, of the University of California, has recently stated that recovery usually varies from 10 to 25 percent, *Science of Petroleum*, I, 541.

[85] This assumes that oil would be produced with dissolved gas only and that the gas pressure in the top of the reservoir sand would be maintained and further that the water-drive would be maintained insofar as possible. Miller, *op. cit.*, pp. 39–40.

[88] Miller, *op. cit.*, p. 40.

In the refining branch of the industry the cracking process alone saved approximately another 1¼ billion barrels of oil in 1937, or as a result of that process one can say the consumption of crude was more than cut in half (fig. 11).[88] Also, had it not been for the cracking process, the industry might have had to produce an even larger extra volume of crude oil in order to have obtained those grades of crude adequate to supply the required volume of gasoline which could be obtained by straight-run production. In the refining process itself, losses of crude oil were cut from 4.3 percent in 1920 to 0.8 percent in 1937.[89]

On the other hand, with respect to use of fuels there has been a decrease in conservation and prudent utilization in that the higher grade and scarcer fuels—oil and gas—have taken over some of the markets for the more abundant supplies of energy—coal and water power.

Beginnings of Conservation

The earliest efforts at conservation are found in State laws. Pennsylvania in 1878 and New York in 1879 passed laws requiring the plugging of wells so as to shut off fresh water from oil-bearing rocks. In 1883 Ohio passed a law requiring the casing of wells so as to prevent fresh water from penetrating the oil sand; Kansas passed a similar law in 1891. A law providing that neither oil nor gas be permitted to flow or escape into the air for a period longer than 2 days was passed by Indiana in 1893.

One of the first cases in which national thought was drawn to waste in the oil and gas industry was in the report of the United States Geological Survey on conservation of resources, published in 1909.[90] This report estimated the loss of gas at 1 billion cubic feet per day (mainly from oil fields). Little was known then of the effect of the loss of this gas on the recovery of crude oil. In 1913 the American Institute of Mining and Metallurgical Engineers created a petroleum committee to study the efficiency of production methods. Attention of trained engineers also was directed to the oil industry by the development in several universities of courses in petroleum geology and petroleum engineering.

In 1913 a method for recovering additional crude was developed by I. L. Dunn, according to which gas or air was injected into the oil sand.[91] By 1916 engineers were beginning to realize that natural gas associated with oil provided the energy for expelling oil from the reservoir. Within a few years it became clear that crude oil could be effectively conserved by restricting the production of gas so that the gas-oil ratio was at a minimum.

Methods for displacing oil from sand by the use of water were discovered accidentally about 1900 and were extensively adopted after the benefits of this field practice were appreciated. In 1917 J. O. Lewis discussed the recovery of oil by water-flooding.[92] Flooding was legalized in New York in 1919 and in Pennsylvania in 1921.

A great interest in conservation developed after 1915 following the rapid decline of flush production in the Cushing field. During the next 4 years the country saw one of its most prolonged shortages; domestic stocks decreased steadily during this period, especially after the United States entered the World War. Moreover, after 1919 domestic production continued to lag behind consumption, and apprehension over the adequacy of future supplies continued. Attention was turned, however, to the possibility of expanding the substantial imports from Mexico and other foreign fields rather than to conservation.

Aside from the acquisition of Naval oil reserves and the creation and activities of the United States Geological Survey and the National Conservation Commission of 1908,[93] the first formal interest of the Federal Government in the conservation of oil and gas probably was the creation (on December 19, 1924, by President Coolidge) of the Federal Oil Conservation Board, consisting of the Secretaries of War, Navy, Interior, and Commerce, to consider the responsibility of the National Government in relation to "the problem of a future shortage in fuel and lubricating oil, not to mention gasoline."[94] Moreover, President Coolidge stated that "it is evident that the present methods of capturing our oil deposits is wasteful to an alarming degree in that it becomes impossible to conserve oil in the ground under present leasing and royalty practices if a neighboring owner or lessee desires to gain possession of his deposits."[95] The Oil Conservation Board proposed many changes in production procedure with the aim of furthering conservation. Moreover, a committee of the Board, including representatives of the petroleum industry and the American Bar Association, drew up a conservation measure which provided for the relief of oil operators from the provisions of the Federal Antitrust Acts and for the legalizing of cooperative unit development in operation of oil and gas pools.[96]

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[87] Victor H. Scales, American Petroleum Institute, "Oil Industry Forges Ahead," *New York Times*, Sunday, November 13, 1938, Section 11, p. 7.

[88] If this process had not developed, the 1937 volume of gasoline would have required the production of another 1¼ billion barrels of crude oil. The crude oil conserved by cracking rose from 13 percent in 1920 to 52 pecent in 1937, these percentages being the ratios of cracked gasoline to total gasoline produced. *Minerals Yearbook, 1938*, pp. 860 and 868; *Petroleum Facts and Figures, 1937*, pp. 107–18.

[89] *Minerals Yearbook, 1938*, p. 862.

[90] *Bulletin No. 394*, reprinted from report of National Conservation Commission.

[91] H. S. Gibson, *The Science of Petroleum*, I, 535.

[92] J. O. Lewis, *Methods for Increasing the Recovery from Oil Lands*, Bulletin 148, 1917.

[93] F. G. Tryon, "Conservation," *Encyclopedia of the Social Sciences*, vol. IV, p. 227; United States Geological Survey, *Papers on the Conservation of Mineral Resources*, Bulletin 394, Washington, 1909.

Influences Stimulating Conservation

Research and technical progress.—The efficiency of producing crude oil and natural gas and their refined products is steadily increasing, both as a result of the adoption of the best current practice and as a result of the continued improvement of methods and equipment. Because of the rapid growth of the oil and gas industry and the accompanying creation of wealth, the leading firms have been able to devote considerable attention and research to production procedures. Moreover, because of the interest of the Government in conservation of an irreplaceable natural resource and because of the fear of a shortage, the Federal and State Governments, through various agencies, have turned their attention to solving outstanding problems in production, refining, and distribution. Notable in this connection have been the contributions of the United States Bureau of Mines, both in developing new techniques and in increasing the efficiency of old ones. The widespread adoption of improved methods of operation has facilitated an increase in the efficiency of producing crude oil and natural gas, especially in those instances where a pool or a comparatively large area has been controlled by one or a very few operators.

One of the most notable examples of efficient operation is the pressure maintenance project in the Sugarland field in Texas.[97] In the Cabin Creek field in West Virginia maximum recovery and minimum cost of production were attained through the economic spacing of wells and through operating individual wells in the most efficient manner. This field was operated as a unit by the single controlling company with the aim of prolonging the life of the reserve as much as possible, so that it could supply oil to the corporation's nearby refineries.[98]

In addition to lowering production costs and raising the relative recovery, technical progress has led to a more rational utilization of oil and gas supplies by means of developing new byproducts and of increasing the yield of the more valuable products. Chapter 3 indicates the progress that has been made in these directions. Similar improvements have been made in the transportation systems.

New consuming industries.—More effective utilization of oil and gas and hence the reservation of supplies for more important uses have occurred as a result of the development of new uses for petroleum products. More effective utilization, for example, has resulted from the recent practice of heating homes and other buildings by using light fuel oils. These oils, for the most part, have been produced from the heavier and less valuable fractions of the crude. Moreover, the production of these lighter heating oils has helped to stabilize the oil industry in that it has decreased seasonal fluctuations in the industry.

Competition from other fuels.—Technical improvements in the burning of coal and in the use of electricity no doubt have led to comparable improvements in the consumption of oil and gas, and hence have had some influence in stimulating conservation. This problem was discussed in chapter 4.

Present State system of proration.—Although the various State systems of restricting production in flush pools were developed primarily for stabilization purposes, in many instances they have made a considerable contribution toward conservation. Much depends on the way in which the system operates. If the well allowables are based simply on a constant amount per well, production restriction may lead to further drilling and thus to waste of the reserve rather than to conservation. On the other hand, if the allowables are based upon some acreage factor or upon estimated underground content, proration possibly may restrict drilling and increase relative recovery. Much depends upon the nature of the underground reservoir and the most scientific rate of flow. Proration laws may be accompanied by other regulations, such as those relating to well spacing, drilling procedure, methods of casing and cementing, water-oil ratios, and oil-gas ratios. Seldom are all these items regulated in any one field. But the time has arrived when all these matters which relate to the saving of the reserve should be included in regulatory practice.

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[94] Federal Oil Conservation Board, *Report I to the President of the United States*, pt. 1, September 1926, pp. 1–2.

[95] *Ibid.*

[96] *Report III to the President of the United States, 1929*, pp. 4, 26–49.

[97] This entire field was controlled by a single operator. The oil was produced with a minimum of gas and most of the gas was returned to the reservoir. S. F. Shaw, "Oil Field Repressuring," *The Science of Petroleum*, I, 577.

[98] This field has been characterized by high recovery at low costs. The production curve has borne little resemblance to the ordinary decline curves of other fields. Indeed, the production in 1925 was approximately the same as in 1917. Federal Oil Conservation Board, *Report I to the President of the United States*, p. 17.

Moreover, the increase in price of crude oil which may result from the restriction of production is likely to facilitate conservation. There is likely to be less waste and better recovery if crude oil prices are at the level of $1 a barrel rather than at the level of 10 cents a barrel. Observance of State regulations concerning production procedures is likely to be greater when prices are at the higher level.

Cooperative production arrangements.—Important achievements in conservation of reservoir energy have been made by cooperation among operators in developing fields as a unit. Principal operators, sometimes after negotiation with the landowners, define the field carefully and then restrict production to those points at which oil can be produced with lowest gas-oil ratios (chapter 3). This plan of operation eliminates unnecessary offset drilling, saves the gas pressure at the crest of the structure and the water pressure in the lower parts of the structure, and, if the lease interests are pooled, may considerably simplify royalty accounting. Moreover, noncompetitive control of a field will allow restriction of production and a saving in storage requirements if the pool happens to be discovered during a period of business depression.[99] Voluntary unit operation of the Ventura Avenue field in California resulted in the closing down of wells producing mainly gas, which was being blown into the air, without seriously reducing production. As a result both the natural gas and the reservoir energy of the pool were conserved.[1]

One of the greatest gains of voluntary unit operation has been in the maintenance of reservoir pressure throughout a field. For example, in the W. I. Cook pool in Shackelford County, west central Texas, a pressure maintenance scheme has been in operation for 10 years, and it is estimated that the recovery of oil from the pool will be nearly three times what it would have been under usual operating conditions.[2]

Voluntary unit operation also has been used for repressuring oil pools. Among several such projects carried on in northeastern Oklahoma, that in the North Avant area in Osage County is one of the outstanding. In order to encourage the three oil companies in undertaking this project, the Osage tribe voluntarily reduced the royalty rate for a short period. Such projects are simplified in that district because the royalty interests already are pooled among the various members of the tribe.[3] Unitization projects also have been successfully carried out by cooperation among producers operating in natural-gas fields.[4]

Inadequacy of these influences.—Although the above influences, as well as some others, have contributed toward the conservation and effective use of oil and gas resources, they are clearly inadequate. To a considerable extent the oil and gas industry is not organized to take full advantage of the great improvements in methods and equipment which have been developed. The present highly competitive nature of drilling operations greatly restricts the adoption of techniques, such as unit operation, which furnish an opportunity for the full use of engineering abilities. On the other hand, the contributions of proration to conservation have been sporadic. If accompanied by well-spacing provisions, proration may be a conservation measure. Even in East Texas it finally provided a means of conserving reservoir energy. In other areas proration has been the constant enemy of conservation; the Oklahoma City field is an example. A voluntary system of production can be adopted only in comparatively rare instances, where an entire pool is under the ownership or lease control of a very few companies. These considerations indicate why the waste in oil and gas production is still a paramount problem for Government action.

Conservation vs. Stabilization

It is wise to point out again that conservation is directed toward better economy through the introduction of superior efficiency, whereas stabilization is an attempt to improve the profitableness of an industry, regardless of any changes in efficiency.[5] Much that has been done in the oil and gas industry in the name of conservation is really stabilization. In times of a shortage of domestic production the rise of a conservation movement is probably intended to increase the relative recovery and the efficiency of use of our oil and gas resources. On the other hand, pleas for conservation which are made by the industry during a period of excess production and of low prices probably are intended mainly for the purpose of obtaining some kind of a system of production restriction. Thus, the interest in conservation in 1931 and 1932 was really a part of the campaign for stabilization measures. There were, of course, flagrant wastes in the industry, and many public officials who joined in the support of proration plans saw a possible opportunity to reduce these wastes. Yet, for the most part, the proposals for unit operation of oil and gas fields were made primarily for the purpose of solving the problem of instability in the industry.[6] The same applies to much of the legislation relating to conservation of oil and gas, passed by the States during the 1930's. Amos L. Beaty, former president of the American Petroleum Institute, testified in the Federal oil inquiry in 1934, that stabilization was the primary aim of the oil companies in proposing Federal quota restrictions on the production of oil and gas.[7]

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[99] An interesting contrast rises between the competitive development of the Wortham field in Texas, in which a large percentage of the production was made immediately and during a period of depressed prices, and, on the other hand, the cooperative development of the Rainbow Bend field in Kansas and the resulting slow, even production of crude, which did not reach a peak until the price of crude was at its best. Federal Oil Conservation Board, *op. cit.*, pp. 17–18. Other instructive examples of cooperative development are the operation of the Wellington Dome field in Colorado under the leadership of the Union Oil Company of California and the development of the Dominguez Hills field in southern California. Fay L. Wright, "Some Economic Aspects of the Community Oil Lease," *A. I. M. M. E., Pet. Dev. Tech., 1925,* pp. 769–778.

[1] J. P. Umpleby, "Production Engineering in 1927," *A. I. M. M. E., Pet. Dev. Tech., 1928*, p. 20. This pool indicated that maximum efficiency may be represented in different parts of the same pool by widely different gas-oil ratios.

[2] Mitchell Tucker, "Cook Field Exemplifies Value of Pressure Maintenance," *Oil and Gas Journal*, January 27, 1938, pp. 176 and 178. Another example of pressure maintenance under a voluntary plan is that of the Keokuk pool in Oklahoma, where a 20-acre well-spacing system was adopted. *Oil and Gas Journal*, March 17, 1938, pp. 46 and 74.

[3] In the South Burbank district unitization with respect to repressuring was undertaken much earlier in the production life of the pool. H. E. Rorschach and E. G. Dahlgren, "Petroleum Development in Oklahoma in 1926," *A. I. M. M. E., Pet. Dev. Tech., 1937*, pp. 440, 441.

[4] Neil Williams, "Conservation and Unitization of Gas," *Oil and Gas Journal*, May 19, 1938, p. 38.

[5] Watkins, *op. cit.*, p. 35.

Watkins and Kemnitzer are no doubt correct in emphasizing that proration is not primarily a system of conservation of resources and that, indeed, it may lead to waste.[8] Clearly proration will bring about poor methods of production if it results in a uniform allowable per well, regardless of the nature of the underground reservoir. Under such circumstances the rate of production for some wells is too low and for others too high. Monthly proration schedules indicate that present State proration schemes are still based primarily upon a more or less constant allowable per well. Under the marginal wells acts of some producing States, the regulatory commissions have little discretion in varying the allowables according to engineering measurements of reservoir conditions. It is incorrect, however, to hold that proration is not making contributions to conservation. Low uniform allowables for wells in flush fields, modified somewhat by gas-oil ratio regulations, serve the purpose of conservation, though not necessarily that of equitable proration. In many fields production restriction undoubtedly has led to the conservation of reservoir energy and to a greater relative recovery than would have occurred under unrestricted, competitive drilling and production of the field.[9] It has also led to the reduction of storage waste and other surface losses. Moreover, there have been collected many valuable data on the behavior of producing wells—data which are necessary to regulation aimed at conservation.

Thoroughgoing conservation legislation, however, would begin with the aim of setting up conditions under which the most efficient systems of production would be adopted. If production restriction were necessary, it could be made effective under such conditions, although it might lead to the complete shutting down of a field rather than to its operation at a wastefully low rate.

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[6] These proposals, however, were rejected by the directors of the American Petroleum Institute, partly on the grounds that unit operation would result in an increase rather than a restriction of production. LeRoy H. Hines, *Some Aspects of Unit Operation of Oil and Gas Pools and Fields*, U. S. Geological Survey, 1934, p. 7.

[7] *Petroleum Investigation, 1934*, pp. 205–6.

[8] Watkins, *op. cit.*, pp. 34–37; W. J. Kemnitzer, *Rebirth of Monopoly*, 1938, p. 118.

[9] See the testimony of H. C. Miller and Ben E. Lindsly, of the U. S. Bureau of Mines, *Petroleum Investigation, 1934*, p. 1305.

CHAPTER 6.—PRIVATE PROPERTY RIGHTS AND PUBLIC POLICY

Freedom of Production—Rule of Capture

The oil industry developed in a period of unrestricted exploitation under the "rule of capture." This idea of ownership originated at a time when almost nothing was known of the conditions under which oil occurs. It is known now that oil occurs in a pool in association with gas or water or with both of these. The oil pool represents a balance of gravitational forces, gas pressure, and water pressure; and oil will remain in place as long as the equilibrium is undisturbed. The release of pressure as a well is drilled causes these forces to propel the oil to the surface. Scientific production would endeavor to utilize this natural energy as efficiently as possible, that is, at a rate of production based on the characteristics of the entire geological unit.

Yet oil acreages are usually divided into small tracts, and, because of the "rule of capture," pools are exploited under a vicious competitive scheme. The "rule of capture" was established by Pennsylvania courts, which based their reasoning on the erroneous logic in the English rule of percolating waters.[1] By other erroneous analogies to wild game [2] and solid minerals,[3] the courts have established the ruling that oil and gas belong to the owner of the well from which they are produced, regardless of whether or not they have migrated from a neighbor's land.[4]

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[1] For the English rule see *Acton* v. *Blundell*, 12 M. & W. 325 (1843). For the extension of the English rule into the American law see *Jones* v. *Forest Oil Co.*, 194 Pa. St. 379, 44 Atl. 1074 (1900); *Williamson* v. *Jones*, 39 W. Va. 231, 19 S. E. 436, 25 L. R. A. 222 (1894). On this general subject see Northcutt Ely, *Oil Conservation Through Interstate Agreement;* Ely, "The Conservation of Oil," 51 *Harvard Law Review*, 1209.

[2] *Westmoreland & Cambria Gas Co.* v. *DeWitt*, 130 Pa. St. 35, 18 Atl. 724, 5 L. R. A. 731 (1889).

[3] *Williamson* v. *Jones*, 39 W. Va. 231, 19 S. E. 436, 25 L. R. A. 222 (1894).

[4] The essential idea in the "rule of capture" is well expressed by the courts in *Brown* v. *Spilman*, 155 U. S. 665, 15 Sup. Ct. 275, 39 L. Ed. 304 (1895): "Petroleum gas and oil are substances of a peculiar

Correlative rights in an underground reservoir are not recognized by the common law. Except as restricted by State legislation each owner is permitted to drill and withdraw oil exactly as he pleases,[5] with no regard whatsoever for the most efficient development of the entire pool. If a landowner should produce oil from a neighboring land, the only recourse the neighbor has is to drill an offset well. Consequently, when a new pool is discovered, each operator races to drain the field before the oil migrates and is produced through a neighboring well. Competitive production results in a waste of the oil, since no operator can retard his production without losing to a neighbor some of his oil.[5a] As an example of such waste, Miller and Lindsly point to the Winkler field in west Texas, which was brought into production in 1927:

> The "law of capture" held sway in the field, and every producer tried to produce the greatest quantity of oil in the shortest time. Two years after the field had reached its daily peak of production (367,000 barrels), it was producing only 40,000 barrels of oil, and over 1 million barrels of water which had to be disposed [of] at considerable expense.
>
> Although the field has produced in excess of 160 million barrels of oil, it is estimated that 75 million barrels of oil will be permanently left in the fields through hasty, reckless, and inefficient production methods, which allowed water to enter the oil sands prematurely and circumvent large areas of productive oil sand.[5b]

The situation is made worse by the division of a pool into many small-tract holdings. The more diversified the ownership in the pool the greater the offset drilling. Instead of spacing being decided on the scientific basis of which arrangement would most efficiently drain the reservoir, wells are drilled near boundary lines of each holding in order to offset drainage by an adjoining landowner. Furthermore, under the present leasing system there is a separation of interests between the owner and the operator of the same tract. In practically all the leases[6] the lessor's rate is a royalty on production, and accordingly, certain express and implied covenants requiring production and limiting the lessee's power to leave oil in the ground become enforceable on behalf of the lessor. There is usually an implied covenant to drill and produce from offset wells; were the lessee desirous of following a scientific pattern of well spacing or retarding the rate of production, he would run the risk of being penalized for breach of the covenant.

The "law of capture," the patchwork of small, scattered holdings, and the leasing system all force operators to produce at as rapid a rate as possible. Accordingly the reservoir energy in new pools is expended at an excessive rate; a large volume of cheaply produced oil floods the market and depresses prices. In ordinary industries this cheap price would tend to cause production to fall off; but in the oil industry, because of the "law of capture" and because of the heavy fixed investment in equipment that cannot otherwise be used, production continues at any price. The competitive forces within the industry do not satisfactorily regulate supply and demand. In the early thirties after production continued to exceed demand and prices fell, the industry began to call for outside regulatory assistance.

State Regulation

Although State oil laws have been passed and sustained as conservation measures, their primary purpose, by and large, seems to have been stabilization of the industry. Before overproduction and low prices became a problem in the oil industry, there were, however, a few State laws dealing with safety measures, prevention of physical waste, and filing of drilling and production records.[7]

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character, and decisions in ordinary cases of mining, for coal and other minerals which have a fixed situs, cannot be applied to contracts concerning them without some qualifications. They belong to the owner of the land and are part of it, so long as they are on it or in it, or subject to his control, but when they escape and go into other land, or come under another's control, the title of the former owner is gone. If an adjoining owner drills his own land and taps a deposit of oil or gas, extending under his neighbor's field, so that it comes into his well, it becomes his property."

[5] In *Barnard* v. *Monongahela Natural Gas Co.*, 216 Pa. 362, 65 Atl. 801 (1907), the courts have said: "* * * every landowner or his lessee may locate his wells wherever he pleases, regardless of the interests of others. He may distribute them over the whole farm or locate them only on one part of it. He may crowd the adjoining farms so as to enable him to draw the oil and gas from them. What then can the neighbor do? Nothing; only go and do likewise. He must protect his own oil and gas. He knows it is wild and will run away if it finds an opening and it is his business to keep it at home. This may not be the best rule; but neither the legislature nor our highest court has given us any better."

[5a] The evil effects of the "rule of capture" were noted as early as 1909. See United States Geological Survey, *Papers on the Conservation of Mineral Resources*, Bulletin 394, 1909, p. 44.

[5b] H. C. Miller and Ben E. Lindsly, U. S. Bureau of Mines, *Petroleum Investigation, 1934, Hearings on H. Res. 441*, p. 1305.

[6] Judson C. Dickerman, "Organization of the Production, Transportation, and Distribution of Natural and Manufactured Gas in the United States of America," *Third World Power Conference*, sec. II, Paper No. 6, Washington, 1936, p. 12; and E. DeGolyer and Others, "Organization of Production, Refining, and Distribution of Petroleum and Petroleum Products," pt. 1, *Third World Power Conference*, sec. II, Paper No. 5, Washington, 1936, p. 3.

[7] In 1878 Pennsylvania passed the first legislative enactment designed to regulate development of gas and oil. It required operators to plug wells in order to shut off water from the oil-bearing rock and also to prevent the escape of water that might be impregnated with salt. New York passed similar legislation in 1879. Ohio in 1883 passed a law requiring the operator, before drilling into oil-bearing sand, to case the well so as to prevent fresh water from penetrating the oil sand. A similar law was passed by Kansas three years later. In 1891 Indiana passed a law preventing the burning of natural gas from torches, and this statute was sustained in *Townsend* v. *State*, 147 Ind. 64 (1897). This same State in 1893 passed a law which provided that neither oil nor gas should be permitted to flow or escape into the open air for a period longer than two days following the striking of the oil. After this period, the substances were required to be safely and securely confined in the well, pipes, or other receptacles. This law was upheld in *Ohio* v. *Indiana*, 1900. An act prohibiting the wasteful escape of gas into the air and providing that water be cased off and abandoned wells be plugged was passed by the Texas Legislature in 1899. A California statute, 1911, prohibits unnecessary,

The first law restricting production was passed in Oklahoma in 1915, when the flush production from the Healdton and Cushing fields created an oversupply of oil on the market. This law declared that all oil produced in excess of market demand was waste.[7a] A few proration orders were issued before the war demands for oil absorbed all the excess oil on the market. The law remained a dead letter until the Seminole field ushered in a new period of heavy flush production in 1926.[8] Between the years 1926 and 1931 a series of new discoveries were made, including the great Oklahoma City and East Texas fields. This flood of oil, coupled with the effects of the depression, weakened the market; and the oil companies discarded "laissez faire" policies and looked to the Government for relief.

Operators and officials of States whose welfare depended largely on the oil industry were anxious to stem the tide of low prices, reduced revenues, and problems of relief. The Governor of Oklahoma declared martial law in the oil fields and ordered the militia to shut in all but the stripper wells until buyers would agree to pay the producers one dollar per barrel for oil.[9] The Texas Railroad Commission made several attempts to stabilize East Texas production but was stopped each time by a three-judge Federal Court. The Governors of Texas and Oklahoma resorted to martial law to enforce production quotas; but the invalidation of martial law in East Texas [10] resulted in a new rise in production, and until 1934 every proration order was struck down by the Federal Court. Finally, in the *Amazon Petroleum Corporation* v. *Railroad Commission* case,[11] the courts sustained a proration order of the Texas Railroad Commission.

The power of the State to restrict production has been sustained on two bases: [12] the State's power to protect natural resources and its power to protect correlative rights of the owners of a common property.

Two things run through most of the State legislation: prevention of physical waste and stabilization of the market. Except for Illinois and California,[13] all the leading producing States today have legislation establishing proration systems. California has the system of voluntary curtailment of crude oil production regulated by the Central Committee of California Oil Producers and administered by an oil umpire.[14] Although, originally proration had been set up to prevent the ruination of the market, legally it has no basis other than conservation.[14a] Until recently the concept of conservation included only the prevention of physical waste, but, the recent tendency is to include economic waste as well. Proration is a device for controlling production from the wells, properties, or fields so that production for the State will not exceed demand. Secretary Wilbur, in an address before the Governors' Conference in Washington, D. C., January 16, 1931, declared that proration had "no connection with producing methods but is the term applied to the effort to allocate the amount of oil which may be taken from any given producing area." The regulatory commission in the State, on the basis of the Bureau of Mines estimate of market demand or on the basis of purchasers' nominations,[15] decides what the State's share of the national demand shall be. After the monthly allowable for the State is established, the commission apportions the allowable among fields and wells. In order to prevent premature abandonment of wells, some of the State laws exempt from regulation all marginal wells [16] and deduct from the total State allowable the sum of the production from the marginal wells.

Proration regulations are based on capacity of the well to produce. There is no uniformity in standards

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wasteful escape of natural gas into the air. Two measures were passed by the Louisiana legislature in 1910 to prevent waste in the production and transportation of oil and gas. It was not until 1920 that the courts upheld an order of the Wyoming commission based on the conservation statute prohibiting the sale of gas for the manufacture of carbon black (*Walls* v. *Midland Carbon Co.,* 254 U. S. 300 (1920)).

[7a] Session Laws of Oklahoma, 1915, chap. 25.

[8] In 1926 Seminole field production reached over 500,000 barrels a day; report of William J. Armstrong, oil and gas conservation officer of the Oklahoma Corporate Commission, September 17, 1938. In the East Texas field production mounted to over 1,000,000 barrels per day in 1931; the price of crude oil dropped from 90 to 10 cents a barrel. Northcutt Ely, "The Conservation of Oil," 51 *Harvard Law Review* 1213.

[9] *Mineral Resources, 1931,* pt. II, p. 554.

[10] *Constantin* v. *Smith,* 57 F. (2d) 227 (E. D. Tex. 1932), affd., 287 U. S. 378 (1922).

[11] 5 F. Supp. 633 (E. D. Tex. 1934). Ely, *op. cit.*, p. 1214.

[12] *Ohio Oil Co.* v. *Indiana,* 177 U. S. 190 (1900); *Lindsley* v. *Natural Carbonio Gas Co.,* 220 U. S. 61 (1911); *Walls* v. *Midland Carbon Co.,* 254 U. S. 300 (1920).

[13] The Sharkey bill (ch. 585, Stats. of 1931), providing for a commission to establish production quotas for the State, was repealed in 1932, largely as a result of energetic opposition by the independent producers, and no official State proration scheme has been in effect since that date. California State Planning Board, *Regulation of Oil and Gas in California,* 1938.

[14] Beginning in 1929, California producers cooperated in order to secure voluntary curtailment. The Central Committee was finally formed in 1933, and according to testimony by Ralph B. Lloyd it has at all times embraced the producers of 90 percent of crude oil production. *Petroleum Investigation, 1934,* p. 2574.

[14a] Although the Oklahoma law in 1915 expressly prohibited production in excess of market demand, the courts held in *Champlin Refining Co.* v. *Corporation Commission of Oklahoma,* 51 F. (2nd) 823 (1931), that the purpose of the law was not price-fixing but rather prevention of physical waste in storage and production.

[15] Previous to the passage of the Arkansas law, February 15, 1939, the Arkansas Board of Conservation adjusted the demand to conform with engineering standards. The demand for the purchase of crude was first heard at the regular monthly State-wide hearing on prorated fields. The behavior of the reservoir under the previous month's allocation was then studied; if the demand could not be met without undue damage to the reservoir, the allowable was set below the market demand. Report by A. M. Crowell, chief conservation agent of Arkansas, to the Arkansas State Planning Board, September 1, 1938. Since the new law emphasizes ratable withdrawals and efficient recovery rather than production in excess of market demand, the Oil and Gas Commission created by the new law has followed a similar procedure in determining the State allowable.

[16] Small wells of settled production, which are usually defined as wells producing below a fixed quantity. In Texas the fixed quantity varies with the depth of the well. Article 6049 (b), par. 1, Tex. Ann. Rev. Civ. Stat. (Vernon, 1937).

among the several States as to the proration formula adopted, and even within the individual States the standards are modified from time to time.[17] In general, the proration formulas are based on one or more of these three factors: per-well allowances, potential, and acreage. Although the per-well method of determining the allowable is the easiest to administer, the procedure is definitely inequitable unless accompanied by well-spacing regulations and uniform reservoir conditions. Alone it does not take into account either the area drained by the well or the relative producing ability of different wells. Frequently, the "potential" method is just as unfair. The early practice was to measure the potential by allowing the well to flow wide open for a limited period, and then to allocate production to it in the proportion that its potential bore to the potentials of all the other wells in the field. Since other more efficient physical gages of potential have been developed, this method is now less wasteful but is still unfair, since the quantity of recoverable oil is not necessarily directly proportional to the well potential. Still another method establishes the allowable on the acreage alone; this method is equitable only if reservoir conditions are uniform. The best allowables consider acreage, wells, and all the elements of the reservoir, such as formation pressure, permeability of the sand, sand thickness, and other factors.

In Arkansas [18] the Oil and Gas Commission prorates production on an acre-pound basis, limited by gas-oil ratios.[19] Before the recent act was passed, the Arkansas Board of Conservation used a 50-percent acreage and a 50-percent reservoir pressure plan for apportioning the allowable among fields and wells. The rate of production from the reservoir was controlled by reference to a composite of average daily figures on gas, water, and oil, all converted to cubic feet under the indicated reservoir pressure. In the main, the average bottom-hole pressure determined what the critical rate of production would be.

In order to restrict production to the State allowable, Texas operators are required to shut in wells on certain specified days. This plan was inaugurated in November 1937, when the Texas Railroad Commission ordered its first Sunday shutdown in east Texas. Since then it has been extended to the rest of the fields in Texas, and sometimes a holiday includes Saturday as well as Sunday.

The formulas which have as their basic unit the individual well encourage the drilling of unnecessary wells to get a greater share of the allowable. "In East Texas alone, 13,000 of the 24,000 wells are said to be unnecessary from an engineering standpoint. They are estimated to have cost $160 million, yet over 1,300 wells are being added to that field each year at a cost in excess of $13 million. In the Oklahoma City pool, where 300 wells would have been adequate, but where nearly 700 were in fact drilled, the wasted investment has been estimated to be in excess of $31 million." [20] Aside from the wasted capital, too many holes might well result in the depletion of reservoir energy, both through an unscientific location of the wells and through a reduction of the allowable and a consequent slower rate of production, which in the case of larger wells might result in the gas bypassing the oil without lifting it to the surface.[21] Therefore, practically all the State laws have some drilling regulations. Certain of these, such as provisions giving low allowables to new wells, as in Oklahoma and Arkansas, or requiring bond of any person or firm engaged in drilling, as in California and New Mexico, tend to discourage wildcatting.

Practically all the States, however, have some spacing regulations, although because of the numerous exceptions granted by regulatory agencies, some regulations are ineffective. For example, in the East Texas field the original order required the spacing of one well to ten acres, yet more than 17,000 of the 24,269 wells drilled in that field prior to January 1, 1938, had been drilled under exceptions allowed by the railroad commission.[22]

Spacing regulations are usually least effective where they are most needed; that is, in fields composed of small tracts. The main difficulty concerns a tract whose acreage is too small to afford even one well. A rigid adherence to the spacing rule without some compensating adjustment to the owner for the oil beneath the land would be clearly confiscatory; on the other hand, granting the permission to drill a well without any protection to the neighboring landowner against undue drainage would also be unsatisfactory, if not invalid. Several plans have been suggested [23] to overcome the problem of small tracts in spacing. Texas adopted a plan whereby the owner of a small tract which was segregated before, or segregated after but developed before, Rule 37, was entitled to the first well as a matter of right. No reduction is made of the allowable, and, furthermore, any owner may obtain exceptions from the spacing rule in order to equalize the well density of his tract with the well density of neighboring tracts. This plan, coupled with the interpretation of the marginal-well statute, which grants a full marginal-well allowance (in accordance with its depth) to any well drilled upon a small tract, results in a virtual abrogation of the spacing regulation.

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[17] At the end of December 1932, the method used for prorating the East Texas field was based on two-thirds well and one-third acreage and bottom-hole pressure. Note, this was the first order to incorporate the acreage and potential factor. In the next year several new methods were tried in this same field. At the beginning the method was based on an allowance for each well with consideration given to bottom-hole pressures. A later proposal gave weight to such factors as sand thickness, permeability, porosity, and saturation, but that method was not sustained in court; and an alternative plan based on the potentials of key wells was substituted. *Minerals Yearbook, 1932–33,* p. 479; and *1934,* p. 675. See also David Donoghue and E. Baker, "Proration in Texas in 1932," *A. I. M. M. E., Pet. Dev. Tech., 1933,* pp. 48, 49.

[18] A restriction formula based 50 percent on acreage and 50 percent on the individual well is in force only in the Rodessa field of Miller County. Report by A. M. Crowell to the Arkansas State Planning Board, September 1, 1938.

[19] The total allowable set for each field is divided by the sum of the acre-pounds, which are determined by multiplying the bottom-hole pressure by the acreage for each producer. *Oil and Gas Journal,* April 6, 1939, p. 24.

[20] By contrast, one writer has said that in New Mexico during the years 1934, 1935, and 1936 some 317 million barrels of reserves were developed with only 820 wells, while in west Texas 288 million barrels of reserves were developed with 2,346 wells. Ely, *op. cit.*, p. 1233.

[21] This applies in particular to wells in which gas is the primary source of reservoir energy.

[22] These were granted in order to prevent interlease drainage. Ely, *op. cit.*, p. 1230.

Another plan provides for a reduction in the allowable. This method works fairly satisfactorily for areas only slightly smaller than the area required under the spacing rules, but in the case of very small tracts the result would be either confiscation or unnecessary wells. The legislatures of New Mexico,[24] Oklahoma,[25] Louisiana,[26] and Arkansas [27] have adopted a third plan, whereby the small tract is denied a well. The small tract may be pooled with adjacent tracts and share in the production from the wells on an equitable basis. Although forced pooling of lots within a city block has been upheld in several cases,[28] it is only recently that a case [29] applying this principle to a small tract in a rural area in Oklahoma was upheld.

Other provisions in State laws dealing with prevention of physical waste include casing requirements, regulations of gas-oil ratios, requirements for taking logs and keeping records while drilling, and other provisions regulating the manner of taking and storing the oil. The States generally have some clause prohibiting the production of oil and/or gas in such a manner as to constitute waste. Most of the laws specifically state that the term "waste" includes production in excess of reasonable demand,[30] underground waste, surface waste, and waste of reservoir energy. All the State laws prohibit unnecessary escape of natural gas into the air. Through the fixing of gas-oil ratios the States restrict the amount of gas produced with oil. Some State laws restrict the use to which gas may be put. A Texas law, for instance, prohibits the use of natural gas for the manufacture of carbon black, until after the extraction of the natural gasoline content from the gas, and rules against blowing gas into the air even after the gasoline content has been removed. Furthermore, the law prohibits the use of sweet gas for the manufacture of carbon black.[31] The Kansas law prohibits economic waste of gas, which is defined as the use of merchantable gas in any manner other than for light, fuel, carbon-black manufacture, and efficient chemical processes or repressuring purposes.[32]

In order to prevent underground waste, which embraces the improper use of reservoir energy, the States provide for water shut-offs and usually require approval by the commission of the method used by the operator. Arkansas controls the rate of water encroachment by means of a control chart, which fixes the critical rate of production.[33] Gas-oil ratios are regulated, and orders for shutting in wells at which gas production exceeds maximum gas-oil ratios have been issued in California.[34] Ingenuity in reducing the ratio is rewarded in Arkansas by increased allowables. All the State laws include regulations requiring operators to use every precaution to prevent blowouts, cave-ins, explosions, and fires. In general, the States regulate abandoned wells and require that wells be plugged in the manner approved by the commission.

If, as some do, we allow the term "proration" to include all the measures passed by State bodies to regulate the oil and gas industry, it is clear that proration has accomplished much in the way of conservation. Strictly speaking, however, proration as a device for limiting production to the demand for crude may or may not have the effect of conserving the crude. J. H. Dunn, production engineer for the Lone Star Gas Co., says: [35] "While there have been some increases in ultimate recoveries under proration, and undoubtedly the producing lives of fields have been extended where production rates have been restricted, it is questionable whether in a majority of our fields ultimate recovery figures have been greatly increased. From the best information available it appears that more than 70 percent of all of the active wells in the United States today are pumping or producing by artificial life, or nearly 250,000 out of a total of over 350,000 active wells." Although proration has some advantages, it is not the final solution to the problem. This is expressed by

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[23] A. W. Walker, Jr., "The Problem of the Small Tract under Spacing Regulations," *Oil and Gas Journal*, August 11, 1938, p. 41.

[24] Ch. 72, sec. 12, laws of New Mexico, 1935.

[25] Ch. 59, art. 1, sec. 3, session laws of Oklahoma, 1935.

[26] Act No. 225, sec. 6, subdiv. 6, acts of Louisiana. R. S. 1936.

[27] An act passed February 15, 1939, sec. 15.

[28] *Marrs* v. *City of Oxford*, 32 Fed. (2d) 134, A. L. R. 1336, cert. denied, 280 U. S. 573; 50 Sup. ct. 29, 74 L. Ed. 625; *Tysco Oil Co.* v. *Railroad Commission*, 12 F. Supp. 202.

[29] *Patterson* v. *Stanolind Oil & Gas Co.*, 77 Pac. (2d) 83 (1938).

[30] This applies to crude oil only.

[31] *Vernon's Texas Statutes*, 1936, art. 6008, sec. 3 (j).

[32] Kansas State Planning Board, *Experience of Kansas under Petroleum Production*, November 1938, p. 7.

[33] Report by A. M. Crowell, chief conservation agent of Arkansas, to the Arkansas State Planning Board, September 1, 1938.

[34] California State Planning Board, *Regulation of Oil and Gas in California*, 1938, pp. 11–14.

[35] "Spacing Regulations Justified under Law, A. B. A. is Told," *Oil and Gas Journal*, August 4, 1938, p. 19.

Joseph E. Pogue, when he says:[36] "Proration results in operation of wells under back-pressures at part capacity. It is well known, of course, that oil wells cannot be efficiently exploited at full capacity, hence the suppression of flush flow, brought about by proration, is a contribution to efficiency. This argument, however, loses some weight by virtue of the fact that the advantages are only a small part of those available under unit operation. Nevertheless, it has come about that some fields, such as Yates, Tex., and Hobbs, N. Mex., have been enabled by proration to simulate unit operation, to the benefit of operators in such areas. This aspect of proration should not be minimized." A recent example of the advantages of proration is found in the Schuler field in Arkansas, where the drastic cut in production recently effected by reduced allowables and curtailed pipe-line purchases resulted in a 7-pound rise in the reservoir pressure of the field. The pressure had been declining at an alarming rate.[37] It will be remembered, however, that Arkansas is the one State which considers reservoir conditions as being more important than the relation between production and probable demand.

This emphasis on engineering factors is a part of the recent tendency in all the States to pass laws based on good engineering principles. The extent of these State provisions (table 11) is summarized in the *Britannica Book of the Year:*[38]

> With the growth of conservation principles, there have come increasing limitations upon, and exceptions to, the rule of oil capture. Today an owner or lessee cannot drill without the permit of a regulatory body; locate a well except as the applicable spacing rule or exception specifies; penetrate surface water sands without a proper casing program and suitable means for shutting off extraneous water; produce a well except through tubing with restricted flow; utilize gas in the reservoir as a lifting agent beyond a permitted gas-oil ratio; currently produce in excess of established allowable production; create fire hazards or waste oil by use of earthen storage; transport by pipe line without a pipe-line permit; dispose of salt water without prevention of pollution; nor abandon a well without proper plugging.

The Secretary of the Interior[39] explained this conservation trend in a statement before a Subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives: "The oil industry, along with the Nation, has recovered from the depressing conditions of 1933 and 1934 to such an extent that the emergency stabilization measures no longer press for attention. On the other hand, the increasing demand for petroleum products and the mounting production has emphasized the need for conservation. I am glad to be able to tell you that there has been an increased appreciation of this fact by the State conservation authorities and by the industry." Evidence of the emphasis on conservation is apparent in a recent Oklahoma amendment,[40] which changes the wording of the 1933 law so that the emphasis is on conservation rather than proration. The "proration umpire" is now called the "conservation officer," and in other places where "proration" was used "conservation" is now used. In the same session the 1933 laws were further amended[41] to extend the definition of waste and thus prohibit "the use of reservoir energy for oil-producing properties by means or methods that unreasonably interfere with obtaining from the common source of supply the largest ultimate recovery of oil." Texas, too, in its 1935 law,[42] prohibits "physical waste or loss incident to, or resulting from, so drilling, equipping, locating, spacing, or operating well or wells as to reduce or tend to reduce the total ultimate recovery of crude petroleum oil or natural gas from any pool, and waste or loss incident to, or resulting from, the unnecessary, inefficient, excessive, or improper use of the reservoir energy, including the gas energy or water drive, in any well or pool." The recent laws of New Mexico,[43] Oklahoma,[44] Louisiana,[45] and Arkansas[45a] which establish proration units of a uniform number of acres and provide for the pooling of properties where the individual tract does not conform to the standard proration unit are a step toward field-wide unitization, a device permitting the practice of the best engineering methods.

Limitations of State Legislation

This recent legislation in the direction of conservation is all well and good as far as it goes. Due to the interstate nature of the oil industry and the competition between the States, it cannot provide a full solution. As Ely says.[46] "* * * no matter how effective the various State systems of conservation may become, no matter how efficiently they may conserve reservoir energy and effect the apportionment of production among separate pools, there are inherent limitations on their individual powers * * *. Self-restriction by one State can no more control the wasteful flush production in another State, despite the effect on their joint market, than it can control the deforestation of a common watershed. * * *. State lines have no influence on the physical effect of these regional forces." This problem of State

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[36] "Economics of Proration," *A. I. M. M. E., Pet. Dev. Tech., 1932,* p. 74. Also, *Petroleum Investigation, 1934,* p. 1274.

[37] "State Capitals." *Oil and Gas Journal,* July 7, 1938, p 24.

[38] Edited by Franklin H. Hooper and Walter Yust, *1938 Britannica Book of the Year,* Encyclopedia Britannica, Inc., 1938, pp. 516–517.

[39] Hearings on S. 790 and H. R. 5366, Washington, April 27, 28, 29, and May 3, 1937, p. 4.

[40] Oklahoma Session Laws, 1935, p. 239, sec. 1 (H. B. No. 274).

[41] Oklahoma Session Laws, 1935, p. 279, sec. 2 (H. B. 187).

[42] *Vernon's Texas Statutes, 1936,* art. 6014 (f) (g).

[43] Session Laws of New Mexico, 1935, ch. 72, sec. 12.

[44] Oklahoma Session Laws, 1935, p. 233, sec. 3.

[45] Louisiana Act 225 of 1936, sec. 6.

[45a] An act passed February 15, 1939, secs. 14, 15.

[46] Northcutt Ely, *Oil Conservation through Interstate Agreement,* Federal Oil Conservation Board, Washington, D. C., 1933, p. 161.

TABLE 11.—*Comparison of State oil and gas conservation statutes and regulations*

Types of provisions	Texas	California	Oklahoma	Louisiana	Kansas	New Mexico	Arkansas
Administrative agency	Railroad Commission of Texas.	State oil and gas supervisor. Voluntary committee[1]—Central Committee of California Oil Producers.	Oklahoma Corporation Commission.	Department of Conservation.	Kansas Corporation Commission.	Oil Conservation Commission.	Oil and Gas Commission.
Methods of determining State allowable.	Discrimination by buyers prohibited. All persons storing, processing, marketing crude, natural gas, or products thereof required to file sworn statements pertaining to market demand. Bureau of Mines estimate adjusted for new foreign markets and other economic and operating conditions.	Bureau of Mines estimate serves as basis for proration measures.[1]	Purchasers canvassed; monthly open and formal hearings with purchasers, producers, and conservation department representatives held. Stocks not considered. Discrimination by buyers prohibited. Bureau of Mines estimate followed as a rule.	Based on market demand on the whole; approximates Bureau of Mines estimate. Rate of production restricted to limit based on restricted drainage areas, efficient gas-oil ratios, prevention and correction of low-pressure areas. Stocks and refinery demands considered. Discrimination by buyers prohibited.	Approximates Bureau of Mines estimate. Based on purchasers' nominations. Engineering factors not considered because allowable is too low. Stocks affect State allowable.	Bureau of Mines estimate taken as prima facie evidence of reasonable market demand. Allowable large enough to maintain reasonable storage.	Demand heard at state-wide hearing. Behavior of reservoir in preceding month considered and a demand which can be supplied without undue damage to the reservoir is determined. Stocks are checked and at present are no problem.
Proration bases for distributing State allowable.	Commission authorized to allocate allowable on a fair and reasonable basis. Reasonable market demand of one pool not discriminated against in favor of another pool. Allowables sometimes adjusted to demand for particular types of crude. Proration formulas vary and include fixed percentage of daily potential, acreage, per well and acreage, potential and acreage. Bottom-hole pressures and sand thickness used at times. East Texas field allowable based on a maximum ultimate recovery rate consistent with maintaining uniform pressure. Allowables for gas wells based on percentage of daily producing capacity; takes into account the size of tract, formation pressure permeability, and porosity of the producing formation, and well bore's structural position. Rate of gas production controlled in Panhandle and Rodessa fields.	Percentage of potential.[1]	Pools divided into 5 classes. Restrictions determined on lease or well basis. Based on percentage of the potential, which must be determined every 6 months by a 6-hour gage usually taken through the tubing.	Gas—percentage of open flow capacity allowable depends on acreage. Oil—field allowable considers well spacing, potential (open flow, full capacity, 5 days), gas-oil ratio, depths of the producing wells, acreage, and sometimes pressure.	Percentage of potential. Fields classified according to average well potential. Group average potential times the number of wells in the classification determines the total group potential. The percentage of market demand allocated is the ratio of the group potential to the total State potential, with exceptions.	Proration unit for each pool established. Pooling of small tracts may be required. Allowable reduced for well on tract smaller than proration unit. Each field's allocation varies to suit field's particular need. Potential usually not used. Bottom-hole pressure decline is considered in order to control reservoir energy.	Rodessa field only—proration based 50 percent on acreage, 50 percent on individual well. All other fields—acre-pound basis (acre-pounds: bottom-hole pressure multiplied by acreage for each producer), with the gas-oil ratio as a compensating factor. Daily allowed production is the critical rate of production based on bottom-hole pressure.

Provisions for marginal wells.	Exempted from regulation. Defined as pumping wells; vary with capacity and depth of well.		Allowable for any well cannot be reduced below 25 barrels daily. Marginal wells exempted from proration. Total production deducted from State allowable	None	Wells producing less than 15 barrels daily are exempted from proration. Total production deducted from State allowable.[1]	Allowable to small wells must be such as will prevent premature abandonment of the wells.	Allowables to small wells must be such as will not accelerate premature abandonment.
Restrictions on production from discovery wells.	New fields not prorated until production aggregates 10,000 barrels per day.	Restriction until increase in demand or decrease in supply warrants production from new fields.[1]	Orders allow new well daily production of 15,000 barrels until the second well comes in in that pool; all wells then cut to 100 barrels daily until reclassified.				
Restrictions on or provisions discouraging wildcat drilling (see provisions above on discovery wells).	Specifically states there is no restriction on wildcat drilling. Must conform to spacing rule of statewide application.	Bond required for drilling or deepening wells. Notice of intention to drill required.	Orders usually establish low allowables for new wells.		No restriction on wildcatting. Drilling within 100 feet of the center of railroad right-of-way prohibited.	Wildcat wells may not be drilled closer than 330 feet to any lease or property line or less than 660 feet from any other well. Notice must be filed of intention to drill. Bond required for drilling.	Permit and fee required for drilling of exploratory wells.
Spacing regulations	Special rules for various fields. Regulations provide a minimum acreage per well, minimum distance between wells and from lease lines. Exceptions granted.	Prohibits new wells from locating within 100 feet of an outer boundary of a parcel of land, 100 feet of a highway, 150 feet of an existing well.	Proration units established. Commission authorized to make 10-acre spacing units; to make spacing units up to 40 acres where 80 percent of the lease owners agree.	Establish proration or drilling units. Makes "pooling" available to owners of small tracts.	No direct law. Spacing orders made under an "acreage factor" used in determining potentials and allowables. Proration units established.	Orders establish spacing—usually 1 well to 40 acres. Proration units established. Well may be drilled on small tract within unit only if it can be done without waste.	Commission authorized to regulate spacing and establish drilling units.
Items prohibited as waste not otherwise included.	Underground waste. Burning wastefully of any natural gas at well. Physical waste. Reduction of quantity of oil ultimately recoverable. Escape of natural gas into the open air. Production in excess of marketing or transportation facilities. Loss due to improper use of reservoir energy. Earthen storage or storage in open pits.	Escape of gas into the air. Unreasonable waste of gas after gasoline is removed.	Economic waste. Underground waste. Waste of reservoir energy. Waste due to production in excess of transportation or marketing facilities. Escape of gas into air. Unnecessary leakage in pipe lines.	Underground waste. Surface waste. Any unreasonable waste of leakage. Escape of gas into open air.	Producing in excess of reasonable demand. Underground waste. Surface waste. Waste of gas energy. Waste incident to production of petroleum. Escape of gas or oil into the air for longer than 2 days.	Underground waste. Improper use of reservoir energy. Any factor reducing the quantity of ultimately recoverable oil. Surface waste. Loss resulting from evaporation, leakage, fire. Storage in open pits, earthen tanks.	Unnecessary escape of gas. Underground waste. Improper use of reservoir energy. Spacing, drilling, operating in any manner which reduces ultimate recovery. Inefficient storing. Abuse of correlative rights. Production methods causing water coning.
Provisions regulating abandoning of wells.	Manner of plugging abandoned wells approved by supervisor of oil and gas.	Approval required before abandonment; plugging must be approved.	Plugging of abandoned wells supervised by the inspector of oil and gas.	Notice required	Written notice required. Plugging methods prescribed and supervised by Commission.	Must be plugged in a manner approved by the Commission.	Permits required for the abandonment of wells. Requires bond conditional on plugging dry or abandoned wells.
Restrictions on gas-oil ratios.	Inefficient gas-oil ratios declared wasteful and prohibited. Wells with excessive ratios penalized in production.	Prohibits unreasonable gas-oil ratios.	Commission authorized to establish gas-oil ratios.	Gas-oil ratios confined within reasonable limits.	Commission has established gas-oil ratios. Prohibits production of gas in excess of maximum ratio determined for common source of supply.	Commission authorized to fix gas-oil ratios.	Commission fixes efficient gas-oil ratios

Footnotes at end of table on page 209.

TABLE 11.—*Comparison of State oil and gas conservation statutes and regulations*—Continued

Types of provisions	Texas	California	Oklahoma	Louisiana	Kansas	New Mexico	Arkansas
Records required	Records of drilling. Many other records also.	Accurate log and history of well.	Metering of gas	Accurate and complete log of wells drilled and deepened. Other records of drilling.	Pipe line maps. Estimated production from wells in prorated pools. Meter charts and records of gas purchased.	Detailed and accurate records of the well; other data also.	Logs and drilling records of wells required. Reports of location of oil and gas wells.
Rules for prevention of water encroachment.	Requires casing in such a manner as to exclude water. Prohibits waste due to drowning of stratum. Requires oil and gas strata to be protected from infiltrating waters.	Method of water shut-off must be approved. Prevention of infiltration of water required.	Commission authorized to make rules and regulations to prevent water encroachment.	Drowning of stratum with water declared wasteful and prohibited. Cementing of water strings of casing by approved methods required.	Law requires casing off of water from oil sands.	Water shut-off must be approved by the Commission. Commission makes rules to prevent drowning or premature water encroachment.	Drowning with water declared wasteful and prohibited. Commission authorized to make rules to prevent water encroachment.
Regulations for prevention of fires and blow-outs (see above on spacing regulations).	Creation of unnecessary fire hazards prohibited.	Strong casing, safety devices, and every effort to prevent blow-outs, explosions, and fires required.	Notification of fires and leaks required.	Commission prescribes regulations for boring to prevent blow-outs and gas wastes.	Setting fire to escaping gas prohibited.	Commission authorized to make regulations to prevent fires, blow-outs, "caving." Storage tanks must be protected by fire walls.	Commission authorized to make regulations to prevent "blow-outs," "caving," "seepage," and fires.
Unitization of tracts	Pooling of small tracts may be permitted though compulsory unitization of fields is prohibited by statute.		Permits owner of small tracts within proration units to pool with majority owner.	Commission authorized to pool leases within proration units.	Recognized, but not compulsory.	May require pooling of small tracts within proration units.	Law requires Commission to pool small tracts within a drilling unit.
Restrictions on use of natural gas.	Natural gasoline must be extracted before carbon black is manufactured. Use of sweet gas for carbon black prohibited. Escape of gas after natural gasoline is extracted prohibited. Flambeau lights prohibited.	Blowing of natural gas into the air, even after extraction of natural gasoline, prohibited.	Use of flambeau lights unlawful. Gas used around derricks restricted. Metered gas only allowed to burn during the day.	Commission authorized to determine percent of natural gas used for carbon black manufacture. Flambeau lights unlawful. Commission authorized to require extraction of natural gasoline before gas is used for carbon black.	Prohibits as economic waste the use of gas other than for lights, fuel, carbon black manufacture, efficient chemical processes, and repressuring purposes. Flambeau lights prohibited. Hearings to determine if proposed utilization is wasteful.	Escape of gas in commercial quantities prohibited.	Wasteful utilization of natural gas prohibited. Use of flambeau lights proscribed. Use of gas for manufacture of carbon black declared waste.
Drilling regulations	Commission issues orders varying according to conditions in the field. Notice of intention to drill required.	Written notice required of intention to drill, deepen, or redrill any well, or remove any part of the derrick, rig, or casing.	Requires notice of intention to drill.	Requires sealing of stratum after passing through sand. Written notice required before disrupting a string of casing. Manner of casing well regulated by Commission. Other orders vary as conditions require.	Must case or plug in such manner as to exclude all salt water from both upper and lower veins.	Manner of casing prescribed. Regulations provide for mud fluid. Wells required to be equipped with tubing. Operators required to outline in detail casing programs—weights, strings, cement, etc. Deviation tests required. Orders vary.	Elaborate casing programs provided. Requires casing to prevent escape of oil or gas out of one stratum to another.
Voluntary unit operation.	Specifically states in oil laws that act does not require unitization of fields. In gas law, unit operation permitted.	Agreements for cooperative development permitted.		Permits pooling of properties.	Unitization of leases permitted by Commission.	Plans for unit operation may be adopted.	Plans for unit operation permitted.

Other legislation	Law fixes maximum sour gas to be produced from a common reservoir producing sweet and sour gas. Operators of plants extracting gasoline from both sweet and sour gas must obtain permits from Commission. Commission authorized to establish rules for shooting wells. Use of vacuum pumps prohibited in some cases.	------	Vacuum pumps prohibited in some cases. Provisions against shooting of wells.	Provides for tenders for transportation.	Increasing flow by artificial means prohibited. Commission regulates water flooding and repressuring. Sour gas in excess of allowable prohibited if merchantable gas is produced from same source of supply. Sour gas may be exempted from use restriction.	Permission required for shooting or chemical treatment of wells.	Commission authorized to regulate shooting, perforating, and chemical treatment of wells; also secondary recovery methods. Commission may require tenders for transportation.

Compiled by Florence Hiller.

Source: Reports to the National Resources Committee[1] from the State planning and regulatory commissions; State statutes; rules and regulations[2] issued by State regulatory commissions; issues of the *Oil and Gas Journal*.

[1] Not part of a State law.

[2] Reported discarded by the *Oil and Gas Journal*, Dec 8, 1938, p. 26.

Note: This compilation is presented as an abstract of major regulatory features of leading oil and gas States. It is not comprehensive but is intended as a guide for the general reader.

lines is emphasized in the Rodessa pool, which stretches across three State lines—Louisiana, Arkansas, and Texas. "At various times each of the three States has enforced a different rate of production on the wells within its boundaries within that single pool. The resultant loss of market by the most conservative State to the most reckless one illustrates in sharper focus the problem presented by more distant pools which are tributary to the same common market." [47] Fortunately, there are few such pools.

The effect of flush production and lack of uniformity of State restriction is to cause the abandonment of stripper wells and thereby lose the reserves reached by those wells. Dr. Katharine Carman, in the Petroleum Investigation,[48] testified that "wells were abandoned in greater numbers in 1931 than ever before in the history of the petroleum industry. In that year 62 percent more wells were abandoned than were drilled in the total United States. The primary cause for these abandonments was the extremely low price prevalent in 1931. The low price was due in part to depressed conditions in general, but in large part to tremendous overproduction and cheap oil in East Texas." In a report [49] of the National Stripper Well Association to the Subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, the interstate character of flush production and its effects on the Nation's reserves is emphasized again. "We can skim the cream off an oil field through excessive production and abandon that field when it ceases to flow. The other alternative is to continue production for all our fields until we have obtained the maximum possible recovery. The latter can only be realized if wasteful methods are held in check by State laws. If oil produced in violation of those laws is permitted to enter interstate commerce, then the problem of law enforcement becomes increasingly difficult and the conservation program of the oil States is defeated." Controlling production, however, is only one phase of conservation. At the present time the industry seems to have been relieved of the depressing conditions which stimulated control legislation. At the present time, too, it is possible to meet the demand and at the same time produce at a rate which will yield the greatest quantity of ultimately recoverable oil. However, as Secretary Ickes [50] observes, "The desire to produce more oil than is technologically good for a well or field may come when the demand for oil exceeds that which may be produced efficiently, when a State may look to an immediate revenue which may be derived from severance taxes on oil, or when one State may endeavor to maintain its output in a constant relationship with that of another State regardless of their comparative ability to produce oil with an equal degree of efficiency." The oil resources of the Nation are of national concern and the program for their conservation should be Nation-wide. This can be accomplished either by Federal legislation or by a system of uniform legislation throughout the States. It seems unlikely that the States will pass uniform legislation except to comply with minimum Federal standards. There is little hope under the present system for an extensive Nation-wide conservation program.

Development of the Federal Interest in Oil and Gas Conservation

Early Interest in Conservation

Early efforts of the Federal Government to increase the efficiency of production of oil and gas have been described in chapter 5.

War Regulation

The problem of obtaining adequate supplies of petroleum products along the Atlantic seaboard accounted for the interest of the Federal Government in the industry during the participation of the United States in the World War. Little effort was devoted to the more efficient production of oil and gas, although the Government was interested in the effective operation of transportation facilities. Soon after entrance into the World War the Petroleum War Service Committee was established in the Council of National Defense for the purpose of facilitating the supply of petroleum products to governmental agencies—primarily to the Navy. In 1918 this Committee was supplanted by the Oil Division of the United States Fuel Administration under the direction of Mark L. Requa.[51] A new committee of oil producers, the National Petroleum War Service Committee, was set up under the chairmanship of A. C. Bedford, chairman of the board of directors, Standard Oil Co. (New Jersey). The industry complained that it could not serve the Government to the fullest extent unless it was excused from the provisions of the antitrust laws. Consequently, an agreement was reached between the Federal Trade Commission and the Fuel Administration, with the understanding that the latter would be the paramount governmental authority over the oil industry during the period of the war.[52]

In the main, the oil industry operated under a system of self-government. For example, all contracts for the divergence of crude oil from its existing channels of manufacture were submitted for approval to committees of the industry, including producers, buyers, and also representatives of the public. Disputed decisions were referred to the Oil Division. Moreover, the industry set up the Atlantic Distributing Committee to maintain the supply of oil along the Atlantic seaboard. The Oil Division allowed this Committee to pool contracts and cooperate in obtaining adequate supplies.[53] At the end of the war the National Petroleum Service Committee became the basis for the creation of the American Petroleum Institute.

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[47] Northcutt Ely, "The Conservation of Oil," 51 *Harvard Law Review,* 1221.

[48] *Petroleum Investigation, 1934,* p. 423.

[49] Hearings on S. 790 and H. R. 5366 (1937), p. 114.

[50] Hearings on S. 790 and H. R. 5366 (1937), p. 8.

[51] *Petroleum Investigation, 1934,* p. 2669; William J. Kemnitzer, *Rebirth of Monopoly,* 1938, pp. 17–18.

[52] *Petroleum Investigation, 1934,* p. 2671; Kemnitzer, *loc. cit.*

Regulations Relating to Federal Lands

Federal laws relating to the search for oil and gas and to production on Federal land were passed in 1920 and have been repeatedly amended. In the main these regulations provide for methods of allocating prospecting permits, for the awarding of oil and gas leases, either with or without competitive bidding, and for the supervision of drilling and production.[54]

For each field or pool discovered on Government land, a representative of the Secretary of the Interior is authorized to require compliance with Government laws and regulations "to the end that all operations shall conform to the best practice and shall be conducted in such manner as to protect the deposits of the leased lands and result in the maximum ultimate recovery of oil and gas with minimum waste.[55]

Federal Oil Conservation Board

On December 19, 1924, President Coolidge established the Federal Oil Conservation Board to study the possibility of a scarcity of oil and to investigate methods for more efficient production.[56] It has been maintained, however, that the major reason for the creation of the Board was the rise in stocks of oil in storage and the weakening in the price structure.[57] Petroleum prices rose considerably in 1925 and 1926. In the latter year the Board held its first public hearings, at which a majority of the industry testified there was no danger of a shortage of oil. Henry L. Doherty, head of the Cities Service Co., however, declared that the Federal Government should regulate the industry because a shortage was threatened and because methods of production were grossly inefficient. Charles Evans Hughes, then representing the American Petroleum Institute, declared that the Federal Government had no power to control production and that the industry could best be assisted by Government permission for intercompany cooperation.[58]

By the end of 1926 discoveries had become so numerous and production of crude oil so great that stocks of oil in storage were rising and prices were falling. In that year the Federal Oil Conservation Board proposed some kind of interstate agreement or compact for the purpose of restricting production and conserving oil.[59] Overproduction of oil occurred during the next few years, and the wholesale price index of petroleum products fell from 100.0 in 1926 to 71.3 in 1929. In that year the Board again proposed an interstate compact to aid in restricting production. Moreover, in 1929 the Board considered a plan of the American Petroleum Institute for world-wide limitation of production to demand. The Attorney General informed Secretary Ray Lyman Wilbur, Chairman of the Board, that the proceedings of the American Petroleum Institute indicated that its purpose in proposing world-wide restriction to the Federal Oil Conservation Board was primarily to obtain from the Federal Government release from the operation of anti-trust laws. Therefore, the Attorney General held that the Federal Conservation Board had no right to approve of any such production-restriction program.[60]

At this point the Federal Government decided it was powerless to restrict production except by obtaining agreements among the producing States. A meeting of the Governors of these States was held in Colorado Springs in 1929 for the purpose of determining how the industry and the States could check overproduction through joint action.[61] The conference failed, and the Board continued its efforts. In 1930 it recommended an arrangement whereby all operators tapping a particular oil pool might come to an agreement upon the amount of oil to be produced within a given period. It was thought a bill could be devised releasing the producers from the provisions of the Federal antitrust acts. Various forms of unit operation were proposed from time to time by the Board.[62]

Production continued to exceed demands and stocks to rise. In 1931 Secretary Wilbur declared that there was no remedy except adoption of an interstate oil compact approved by Congress.[63]

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[53] *Petroleum Investigation, 1934*, p. 2674; Kemnitzer, *op. cit.*, p. 20. At the end of the war, Mr. Requa was cooperating with the industries on a plan to set up a world marketing organization for the purpose of acquiring foreign properties and of supplying foreign markets as well as the domestic market with foreign oil. *Petroleum Investigation, 1934*, p. 2675; Kemnitzer, *op. cit.*, pp. 20–21.

[54] U. S. Department of the Interior, General Land Office, *Regulations Concerning Oil and Gas Permits and Leases and Rights of Way for Pipe Line*, Circular No. 1386, approved May 7, 1936. Greater detail on some matters is given in a previous set of regulations, Circular No. 672. The U. S. Department of the Interior, Geological Survey, *Oil and Gas Operating Regulations, Applicable to Lands of the United States and to All Restricted Tribal and Allotted Indian Land (Except Osage Indian Reservation)*, revised November 1, 1936.

[55] *Ibid.*, p. 2. In this connection the supervisor collects all necessary operating and production data, including rental and royalty records.

[56] *Report I to the President of the United States, 1926*, p. 1.

[57] Kemnitzer, p. 53. The wholesale price index of petroleum products had fallen from 102.9 in 1922 to 83.5 in 1924, the average for 1926 being taken as 100, U. S. Department of Commerce, *Survey of Current Business*, 1936 supplement, p. 13.

[58] Federal Oil Conservation Board, *Public Hearings*, May 27, 1926, pp. 13–23; Kemnitzer, pp. 53–54.

[59] Northcutt Ely, *Oil Conservation Through Interstate Agreement*, Federal Oil Conservation Board, 1933, p. 19.

[60] *Ibid.*, p. 17.

[61] *Ibid.*, pp. 18–19.

[62] The most detailed suggestions are included in *Report III to the President of the United States*, 1929, pp. 1–8 and appendices A and B.

In 1931 the Governors of the midcontinent area proposed an interstate compact paralleling the plans of the Federal Oil Conservation Board. The plan was considered by the Board in April 1931.[64] The Governors set up an oil States advisory committee which entered into an informal production accord in September 1931. This accord lasted to the end of 1932 and had some effect in controlling production in the midcontinent area.[65]

The National Industrial Recovery Act

Soon after coming into office in March 1933, the new administration was concerned with the economic condition of the oil industry. The Secretary of the Interior called a conference of the Governors of the oil-producing States on March 27 to discuss production restriction. (On this entire subject, see pt. four, sec. II, of this report.) At this meeting a committee of officials and producers recommended Federal prohibition of the transportation in interstate and foreign commerce of products produced in violation of State laws. Bills were introduced in Congress providing for such a restriction. But at the suggestion of the President the regulation of the oil industry was made a part of the National Industrial Recovery Act. Section 9 (c) of that act provided for the prohibition of the transportation in interstate and foreign commerce of oil produced in excess of the amount permitted by the proration laws and regulations of individual States.[66] Under this act the Secretary of the Interior regulated the movement of oil in interstate and foreign commerce on the basis of affidavits of legality as to the conditions under which the oil was produced. Operation of this system was restricted to the East Texas field. The system of affidavits proved inadequate and was supplanted by the Federal Tender Board in October 1934. The new system was effective in restricting the production of "hot oil," that is, oil produced under illegal conditions.

This first Federal Tender Board ceased to function January 7, 1935, when the Supreme Court declared section 9 (c) invalid because of improper delegation of legislative authority. Another tender board was later created under the Connally Act.

Code of Fair Competition

The Code of Fair Competition for the Petroleum Industry became effective September 2, 1933, and thus the power of the Federal Government was again thrown behind the proration program. The code provided for limitation of imports of crude oil and oil products, for restrictions on the withdrawal of crude petroleum from storage, for periodic estimates of the domestic output required to supply consumer demand, for allocation of the estimated required production among the several States, for allocation of the allowable requirement among pools and wells within the State, for the supervision of the distribution of allotted production among refineries, for investigation of transportation rates, and for the operation of newly discovered fields in accordance with a plan approved by the President. Moreover, it contained provisions regarding control of prices, whereby the price of crude petroleum was tied to the wholesale refinery price of gasoline. Sale below cost was prohibited.[67] Yet in the main the petroleum code was a means of prorating allowed production among producing districts. The Code became inoperative on May 27, 1935, when the United States Supreme Court invalidated the National Industrial Recovery Act in the *Schechter* case.

The Connally Act

Before the invalidation of the N. R. A., Congress had passed, on February 22, 1935, the Connally Act as a substitute for section 9 (c). It specifically prohibited interstate or foreign commerce in hot oil. A new Federal Tender Board was set up in East Texas, and the Tender system has continued to function since that time. The Petroleum Administrative Board in the Department of the Interior was reestablished as the Petroleum Conservation Division on April 1, 1936, to aid the Secretary in the enforcement of the new act. To date the tender system has been used only in the East Texas field, and of the oil for which applications for tenders have been received, approval has been withheld on only 1 percent of the volume. Fields other than East Texas, however, have been under the observation of the Tender Board and the Petroleum Conservation Division. The Connally law, which was to have expired on June 16, 1937, was extended to June 30, 1939. The main purpose of the law is to stabilize production, although it undoubtedly has promoted conservation, at least in a roundabout manner.

Federal interest in oil and gas conservation has depended primarily on legislation and regulations supplementary to those of the State government, although Federal agencies have made important contributions in technical assistance toward more efficient production and more effective utilization.

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[63] He recommended that the compact provide for unit operation, National Industrial Conference Board, *Oil Conservation and Fuel Oil Supply*; Laidler, p. 31; *New York Times*, January 17, 1931.

[64] Ely, *op. cit.*, pp. 19–20.

[65] For an account of the cooperation between volunteer committees of the industry or of producing States and the Federal Oil Conservation Board, see *ibid*, pp. 21–24.

[66] Sec. 9 also included provisions authorizing the President to regulate the operation of pipe lines and furthermore to institute proceedings to divorce from any holding company any pipe-line company controlled by it (pt. four, sec. II, p. 393 of this report).

[67] National Recovery Administration, *Code of Fair Competition for the Petroleum Industry*, 1933; George W. Stocking, "Oil Industry," *Encyclopedia of the Social Sciences*, XI, 446. Other provisions covered administrative machinery and labor regulations.

Present State-Federal System of Regulation

Since the invalidation of the Code of Fair Competition, the oil industry has been regulated by a State-Federal system. This system is made up of four parts: Bureau of Mines estimates of demand, the Interstate Oil Compact Commission, State proration and regulation, and Federal regulation of imports and of interstate commerce in oil.

Bureau of Mines estimates of demand

The estimates of market demand for crude oil issued by the Bureau of Mines are based primarily upon the demand for gasoline and fuel oil and, to a lesser extent, upon the demand for other petroleum products. The method used is described in considerable detail in part four, sec. III, ch. 2, of this report.[68] The procedure has been highly accurate.[69] For both 1937 and 1938 the Bureau of Mines estimate on the total gasoline demand varied from the actual by considerably less than 1 percent. The close correspondence between the Bureau of Mines estimate, the State allowable, and the actual production for each month can be seen in the tabulation presented by the Bureau of Mines.[70] During the period from 1935 to 1937, the Bureau of Mines estimate was almost invariably slightly lower than actual production. With the restriction in demand since the fall of 1937, however, actual production in many months has been less than the estimate. The forecasting service for gasoline and crude oil demand has been in operation in various forms since 1930. In that year the Federal Oil Conservation Board organized a voluntary market committee, which, with its successors, published reports covering the period from April 1, 1930, to June 30, 1933.[71] The estimating of demand was taken over in 1933 by the Bureau of Mines and became the basis of national planning in the oil industry. This fact-finding work of the Bureau of Mines has been satisfactory to State officials and oil producers alike. (See pt. four, sec. III, ch. 2, of this report.)

Interstate Oil Compact Commission

On February 16, 1935, the States of Texas, California, Oklahoma, Kansas, and New Mexico agreed to form an interstate compact obligating each State to enact conservation laws relating to oil production. The compact was ratified by all the above States except California and by Colorado and Illinois. Contemplated uniform conservation laws, not yet formulated, were to prevent certain kinds of waste.[72]

In its fifth report the Federal Oil Conservation Board recommended the creation of a compact which would obligate each member State to enforce production quotas agreed upon by a joint Federal-State research organization. As actually organized, the fact-finding body is wholly Federal. The interstate body is without Federal participation, and the States are not committed to accept or enforce quotas.[73] As already indicated, however, the recommendations of the Bureau of Mines are put into effect by both members and nonmembers of the compact. Although the stated purpose of the agreement between the compacting States has been to conserve oil and gas by preventing physical waste, the organization has acted primarily as an agency for bringing about the joint acceptance of the Bureau of Mines figures.[74] The compact has cooperated with the Federal Government in the collection of data, particularly in studies of the quantity and characteristics of crude oil in stocks, and in this connection its interest has been in furthering conservation as well as in studying the problem of stabilization.[75] In the main, the compact has functioned simply as a clearing house for information and as a group for making recommendations, either to the Federal Government or to the State governments.

State Proration and Regulation

The whole regulatory system is based upon the existence of power in the State to restrict production, the Federal regulatory efforts being entirely supplementary. The legal bases, as well as the devices by which different States regulate the oil industry, have been discussed elsewhere in this section. (See above and ch. 7.) As already indicated, State proration is based upon the estimates of the Bureau of Mines. Through October

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[68] Also see *Transcript of the Proceedings of the Interstate Oil Compact Commission* at Colorado Springs, Colo., July 29, 1938, pp. 33ff. The mechanics of determining demand are also described by Miller and Lindsly, *Petroleum Investigation, 1934*, pp. 1298ff.

[69] Thus the increase in the stocks of all oils between April 1, 1937, and April 1, 1938 (about 45,000,000 barrels) converted into crude oil equivalents, very closely approximated the excess in crude production above the estimates of market demand. *Transcript of the Proceedings of the Interstate Oil Compact Commission*, January 18, 1938, pp. 20ff.

[70] *Minerals Yearbook, 1937*, p. 981, and *Minerals Yearbook, 1938*, p. 819.

[71] Although price and production fluctuated widely during that period, the estimates were never less than 95-percent accurate, even though they were wholly advisory and informal. Northcutt Ely, *Oil Conservation Through Interstate Agreement*, 1933, pp. 238, note 1, 261.

[72] Interstate Oil Compact, Article I, *Transcript of Proceedings, Interstate Oil Compact Commission*, May 10, 1937, p. 38.

[73] Ely, 51 *Harvard Law Review*, p. 1216.

[74] Although no mention is made in the compact of proration or allocation of the production quotas among States, the Texas Senate on May 7, 1937, authorized the Governor to cancel membership in the compact at any time that Texas failed to obtain a reasonable quota; see pt. four, sec. III, p. 398, of this report.

[75] *Minerals Yearbook, 1937*, p. 980.

1936 these estimates included allowances for changes in crude-oil stocks, and consequently the estimates represented required production. Since that month, however, the forecasts represent the total amount of crude oil required to meet the demand by States of origin, whether produced or obtained from storage. (See pt. four, sec. III, of this report.) Of course, changes in stocks are minor compared to the volume of actual production.

In most producing States the estimate of the Bureau of Mines is not accepted exactly as the State allowable. The State regulatory body usually holds hearings of producers and buyers of crude oil in trying to estimate the market demand for the subsequent month. In some States buyers are required to give sworn statements of their estimates of market demand. It usually happens, however, that these hearings result in comparatively minor change in the figure issued by the Bureau of Mines.

Federal Regulatory Functions

In the general proration scheme the Federal Government performs two functions, the restriction of imports and the prohibition of interstate commerce in hot oil. Imports were taxed 21 cents a barrel under the Revenue Act of 1932, as a result of a plan of the Federal Oil Conservation Board.[76] The tax was reenacted in 1935 and again in 1937. Imports, however, account for only a very small portion of the total supply of oil (ch. 4).

Nevertheless, the Interstate Oil Compact Commission holds that continued restriction of imports is necessary "in planning the proper conservation and development of the petroleum industry" (pt. four, sec. III, ch. 1, of this report).

The prohibition of interstate commerce in oil produced in violation of State production quotas is provided for in the Connally Act, already discussed. This prohibition is usually considered a necessary supplement to State regulation, and its indefinite extension was unanimously approved by the various members of the Interstate Oil Compact Commission.

Attention is now directed to the need for more comprehensive legislation relating to the conservation of oil and gas resources.

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[76] Ely, 51 *Harvard Law Review*, p. 1217.

CHAPTER 7.—PROPOSALS FOR PETROLEUM AND NATURAL GAS CONSERVATION

Need of Federal Regulation

Inadequacy of Present State-Federal System of Regulation

The problem of conservation has not been solved under the present State-Federal system of regulating production in the oil industry. The States have passed many laws concerning methods of operation and protection of reserves, but probably the States' main interest has been in restricting production in order to raise the price or to keep it from falling. In general, production has been kept within bounds, and since 1929 excessive stocks have been reduced materially. Each State has been interested in obtaining as large a share of the national output as possible without jeopardizing the value of its volume of production. The desire of the State to obtain tax income from the industry probably has led it to underestimate the importance of conservation of reserves. Most of the States have been reluctant to restrict production unless comparable restrictions were applied to adjacent States; moreover, they have been unwilling to accept the Federal Government's determination of how much oil the individual States should produce, although during and since the N. R. A. they have continued to accept the Bureau of Mines' monthly suggestion as a basis for arriving at the total allowable. Yet competitive interests of the various States have held back the adoption of comprehensive conservation regulations.

Legislative enactments empowering State commissions to compel proration of oil pools have resulted in savings in many instances. Likewise, control of well spacing undoubtedly has furthered conservation, but as yet no State has attempted to solve the problem by a comprehensive scheme of requiring the most efficient production of the limited reserves of oil and gas. Rarely has a State made an attempt to retard the bringing into operation of new fields, even though the new supplies might mean an unscientific restriction of production in older fields.

Under the present Federal-State system of proration, the initiative lies with the States, and the Federal Government is unable except by suggestion to initiate any general improvement in production procedure or in standardized regulation of the industry throughout the country.

Under the Connally Act, Congress has, in effect, delegated to State legislatures the regulation of interstate commerce by sanctioning their determination of the amount of oil which may be permitted to flow in the channels of interstate commerce.[1] When legislation in the oil industry was being considered in 1933, Secretary of the Interior Ickes reported that the President desired that the prohibition on interstate shipments of petroleum and its products apply to oil and gas produced in violation of any Federal, as well as State, law. At that time the President maintained that State action was inadequate to bring order out of chaos in the oil and gas industry. (See pt. four, sec. two, p. 393 of this report.)

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[1] Sec. four of the act, however, does authorize the President to suspend the act whenever he finds "that the amount of petroleum * * * moving in interstate commerce is so limited as to be the cause * * * of a lack of parity between supply * * * and consumptive demand." This standard has been considered too indefinite. See Myron W. Watkins, *Oil: Stabilization or Conservation?* (New York, 1937), p. 58.

Nor, as indicated in the preceding chapter, has the Interstate Oil Compact Commission been successful in raising production standards among its member States. Indeed, this organization does not appear to be particularly interested in the problem of conservation except insofar as it relates to the restriction of production to a market demand that will yield a satisfactory price.

The Advantage of Federal Regulation

If conservation measures are to apply uniformly to the oil and gas industry, only the Federal Government can be expected to initiate them. The competitive interests among producers and States are so strong that in the main they preclude the adoption of thoroughgoing conservation measures. The oil and gas industry in all its branches is national in character.

Whenever the general public becomes sufficiently impressed with the threatened shortage of petroleum products and the possible rises in prices for motor fuel, the complex problem of regulating the oil and gas industry is likely to be transferred to the Federal Government. It is rather surprising that such a basic industry has not been the subject of more adequate State and Federal regulation. All the automobiles of the country, all aircraft, all naval vessels, and, indeed, over 80 percent of all the Nation's installed horsepower, fixed and automotive, are dependent upon petroleum.[2] The petroleum industry is surely as essential to the national economy as the electric-power industry or the bituminous-coal industry. Yet these industries which depend upon a permanent supply of falling water or on almost unlimited supplies of coal have been subject to all sorts of regulatory efforts, whereas the petroleum industry, "which delivers energy by the exhaustion of a limited resource, is governed only by the laws which it has itself invoked."[3] Threatened increases in prices of petroleum products may in time lead to a reaction against the control of production by the producing States alone.[4] In addition, any serious national emergency is certain to call forth Federal intervention. The sooner preliminary regulation of the industry is initiated, the greater will be the savings in conservation and the more immediate the effective solution of regulatory problems. Oil and gas are products which concern the welfare and comfort of the great majority of the people and which are vital both in industry and in national defense. The question of whether the Federal Government has power to conserve oil and prevent waste will be discussed in a later section. At this point it is clear, however, that only the Federal Government can provide a uniform system of control and regulation.

The proposals in the next section do not necessarily require Federal legislation. Although most of them could be most effectively regulated by Federal measures, much could be accomplished by State efforts. And in some cases, as in changing from the law of capture to the rule of ownership in place, State legislation is clearly called for; even here, however, this change might be stimulated by a Federal system of regulation which required the adoption of minimum conservation laws subject to the approval of some Federal agency. In the main, however, the regulation of the oil and gas industry should be under a State-Federal system in which the superior power to regulate is with the Federal Government and the actual administration with the State governments acting in compliance with minimum Federal standards. The change from the present system does not necessarily need to be drastic, although more uniformity and better coordination are imperative.

Specific Proposals

The general goal of the proposals discussed in this section is to eliminate waste of oil and gas resources and to stretch the life of underground reserves over as long a period as possible without unduly restricting the more important uses of the products of these resources. Effective conservation would provide that reserves be produced in such a way that the maximum percentage is recovered by ordinary methods and that the balance of underground reserves is left in shape for later production if secondary recovery operations are favorable or become desirable because of rising prices. If the suggested changes in legislation and regulation can be effected, the remaining oil reserves can be developed more efficiently and with higher relative recovery than has characterized practice in the past in this country or in a majority of foreign countries. The following proposals encompass also the prudent utilization of the recovered petroleum and natural gas so that more urgent uses be given priority and so that a considerable portion of the heavier and less valuable oils be obtained from abroad. The suggested legislation is based on the conviction that private rights in the control and production of petroleum must be so modified that the Nation can defend itself against the physical waste and uneconomic uses of these irreplaceable resources.

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[2] United States Geological Survey, *Water Supply Paper No. 579*, (1923). When that paper was written, there were less than 18,000,000 automobiles in use. Now there are nearly 30,000,000. Also see ch. 1, p. 124, and footnote 6.

[3] Northcutt Ely, "The Conservation of Oil," 51 *Harvard Law Review* 1242. Among many reasons why oil and gas have been less subjected than coal to Federal regulation may be cited the less serious labor problem in the petroleum industry and the increasing volume of oil and gas products at decreasing prices.

[4] R. W. Fair, member of the tender committee in the East Texas pool, testified that in his opinion State regulation of the oil industry was incapable of solving the problem of conservation. *Petroleum Investigation, 1934, Hearings on House Res. 441, 73rd Congress*, pp. 2019–2023.

The most important proposal of this study relates to the introduction of unit operation of oil pools under the immediate supervision of State commissions which require the observance of satisfactory engineering practices. Unit operation, then, is the opposite of the present competive system of wastefully developing oil pools. The second proposal relates to the adoption of certain minimum engineering standards by State and Federal regulatory bodies, which are to apply to the development and operation of oil and gas fields. The third proposal relates to the restriction of abandoning old oil and gas wells as long as they are still in a state of production. Another proposal relates to the methods by which production can be most satisfactorily restricted to current needs. This proposal provides for the Federal determination of the production quotas for each State and for a State allocation of these quotas based primarily on acreage allowables or on some other approximation of oil in place. Regulation of production should be aided by a rational policy on exports and imports, undertaken with the aim of conserving the Nation's reserves. With respect to the use of petroleum products it is proposed that consumption be restricted to more urgent needs and that the cheaper and more abundant supplies of fuel be used wherever they can. In addition, this report recommends continued Government research in production and distribution methods of the oil industry, as well as further investigation of the public interest in the adequate regulation of the oil and gas industry.

Unit Operation

Description.—By unit operation is meant the development as a whole of a geological unit according to a definite program supervised by the State, royalties to be shared on the basis of acreage, oil in place, or some general equitable arrangement regardless of the location of producing wells.[5] The English refer to unit operation as scientific unit control.[6] Unit operation is recommended here primarily as a conservation measure, although it may serve the purpose of more effective stabilization of the industry and has been advocated at different times for this purpose.[7]

Unit control may be set up by fields or by districts within a field according to position on the structure. In the latter case the unit sections should be selected so that subsurface conditions are nearly uniform and so that production can be allotted on an acreage basis.[8] Separate unit plans are needed for each separate structure. Thus, in the Kettleman Hills district separate unit agreements applied to the North Dome and to the Middle Dome.[9] Unit operation may be comparatively easy to organize in districts wherever most of the land is owned by one or two persons and leased to only a few operators or wherever the Federal Government is the largest land owner.[10]

The major characteristics of unit operation are preliminary exploration in the case of new fields, compulsory pooling of interests, proper well spacing, acceptance of standard development and production methods, controlled withdrawals, and scientific control. Although unit operation may be established in old pools and even in new pools without preliminary study of reservoir conditions, careful definition of the pool limits and of the nature of the reservoir are desirable preliminaries. Accordingly, all commercial exploitation should be delayed until these ends are achieved and, of course, until a satisfactory agreement has been reached defining each owner's proportionate share of the reservoir content, subject to revision from time to time in the light of additional experience.[11]

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[5] W. P. Z. German, "Compulsory Unit Operation of Pools," *Oil and Gas Journal,* March 19, 1931, p. 26; Samuel B. Pettengill, *Hot Oil,* 1936, p. 209; see definition in *A. I. M. M. E., Pet. Dev. Tech., 1930,* p. 11, quoted by H. C. Miller and Ben E. Lindsly, U. S. Bureau of Mines, *Petroleum Investigation, 1934,* p. 1251; also Sir John Cadman, "Conservation of Petroleum," *Third World Power Conference,* Section IV, Paper 12, p. 3.

[6] Thus, the concept includes "the application of a systematic and formulated method of extractinb oil (and/or gas) from a natural reservoir, which is usually referred to as a pool and is the obvious unit for this operation." H. S. Gibson, "Scientific Unit Control," *The Science of Petroleum, I,* 534.

[7] See, for example, Leonard Logan, "Stabilization of the Petroleum Industry," *A. I. M. M. E., Pet. Dev. Tech., 1931,* pp. 618–24; also Pettengill, *loc. cit.,* Miller and Lindsly, *loc. cit.,* George W. Stocking, "Stabilization of the Oil Industry: Its Economic and Legal Aspects," *American Economio Review,* Supplement, March 1933, p. 70; Robert E. Hardwicke, "Legal Aspects of Gas Conservation," *Oil and Gas Journal,* June 25, 1931, p. 126; U. S. Bureau of Mines, "Conservation of Petroleum and of Natural Gas," *Third World Power Conference, 1936,* sec. IV, Paper 12, p. 25.

[8] R. M. Barnes and A. H. Bell, "Proration of an Oil Field Based on Uniform Allowable Gas Production," *A. I. M. M. E., Pet. Dev. Tech., 1933,* pp. 142–147.

[9] LeRoy H. Hines, *Some Aspects of Unit Operation of Oil and Gas Pools and Fields,* U. S. Geological Survey, 1934, pp. 25 and 28.

[10] For example, in parts of west Texas and western Kansas a single ranch encompasses an entire pool. In both of the Kettleman Hills unit agreements the Federal Government was the dominating influence in bringing about unit operation.

[11] In addition to a plan of efficient extraction and of equitable apportionment, the procedure should make provision for allocating the costs incident to exploratory development; for other suggestious see C. M. Neckerson, "Cooperative Development Plan for Buena Vista Hills Oil and Gas Field, Kern County, California," *A. I. M. M. E., Pet. Dev. Tech., 1937,* pp. 183–91; O. E. Kiessling, "Cooperative Development of Oil Pools," *A. I. M. M. E., Pet. Dev. Tech., 1927,* pp. 779–81; Joseph Jensen, "Unit Operation in California, with Discussion of Kettleman North Dome Association," *A. I. M. M. E., Pet. Dev. Tech., 1931,* p. 86.

Effective unit operation requires the compulsory pooling of both operating and lease interests. Such an arrangement undoubtedly would require State legislation providing for unit agreements and new lease forms to replace present lease obligations.[12] By requiring uniform arrangements the State facilitates greater returns to individual land owners.[13] In the application of a unit scheme the law can declare the correlative rights of the various owners in the pool, and can make the respective owners tenants in common on the basis of proportional determination of the contents of the pool.[14] Compulsory cooperation among adjacent land owners is a well-known legal procedure. For many centuries it has been a recognized function of government to prescribe regulations for the better and more economical management of properties which adjoin or for some other reason can be better managed or improved by joint operation.[15] The police powers of the State clearly extend to the conservation of its natural resources.[16] Under their police power the States can prescribe methods for the extraction of oil and gas from a common pool on either of two bases: to protect the public interest against waste, and to insure a just distribution among collective owners.[17]

A voluntary unit operation scheme has been demonstrated to be inadequate for the purpose of achieving important gains in oil conservation on a Nation-wide or State-wide basis. A voluntary scheme is easily blocked or may be subject to dissolution because of the lack of trust among the participators. In the United States owners of diversified lands have not shown much willingness to form unit schemes.[18] In many respects voluntary unit operation is more desirable than compulsory unit operation, but it cannot be achieved except in rare instances.

Effective unit operation requires the combining of all titles or interests in the area so that it may be developed and operated as one property for the benefit of all interested parties. The unitized area should be developed as if it were a single tract held under a single oil and gas lease.[19]

The advantage of compulsory unit operation is considered so great that England, in making provision for any possible oil field which may be discovered in Great Britain, has provided in the British Petroleum Regulations of May 15, 1935, for cooperation among lessees of one geological unit, to be effective at first voluntarily, failing which the Government, through the Board of Trade, has the power to require unit operation subject to the right to arbitration.[20]

Under unit operation wells would be spaced according to the conditions of the reservoir without any regard to property lines. Offset drilling, of course, would be abolished. Unit operation would make it possible to begin operations with a few wells and to drill additional ones as the more complete discovery of reservoir conditions made such action advisable.

Within a field all operations would be governed by proper methods. The same production procedure would be followed under comparable conditions. Moreover, withdrawals from the reservoir could depend upon changes in reservoir conditions and not upon any necessity of avoiding drainage to adjacent properties. Maximum recovery could be accomplished by coordinated operation of wells.

These characteristics of unit operation would not achieve a great degree of conservation unless linked with scientific control of the field. The geologic data should be collected immediately upon the discovery of a new field. The field should be defined and reservoir conditions determined before commercial production is undertaken. Rarely is such a procedure followed even under unit operation, because the invested capital demands a quick return.[21] If commercial production is begun gradually, however, satisfactory information can be collected concurrently. Production procedures should vary with the performance of test wells. Commercial production can be undertaken through a minimum of producing wells, although in addition, a number of observation wells will be needed in order to keep a running check on fluid movements in the reservoir. Such information will allow production to be distributed so as to maintain the field in fluid balance. Repeated analyses of the physical properties of the oil and gas are necessary in determining production methods, which can be varied as operations proceed.[22]

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[12] New lease forms should, for example, excuse the lessor from the necessity of drilling a well.

[13] It would not be necessary for each lease holder to drill a test well.

[14] Earl Oliver, "Can the Rule of Capture Be Rationalized?" *A. I. M. M. E., Pet. Dev. Tech., 1937,* p. 151; Charles G. Haglund, "The New Conservation Movement with Respect to Petroleum and Natural Gas," 22 *Kentucky Law Journal,* 564, 565 (May 1934).

[15] Oliver, *op. cit.*, p. 143.

[16] "Under these powers the State Legislature may regulate and restrict the use and enjoyment by land owners of the natural resources of the State, such as oil, so as to protect them from waste and prevent the infringement of the rights of others. Such legislation does not infringe the constitutional prohibitions against taking of property without due process of law, denial of the equal protection of the laws, or taking property without just compensation." Hines, *op. cit.*, p. 11, and cases cited there.

[17] Hines, *op. cit.*, p. 12 and cases cited there.

[18] See Oliver, *op. cit.*, p. 147; U. S. Bureau of Mines, "Conservation of Petroleum and of Natural Gas," p. 26; Hines, *op. cit.*, p. 13.

[19] Hines, *op. cit.*, p. 8. It might be possible to achieve a kind of unit operation by the pooling of operating interests alone, but in that event the State would have to stand ready to force the pooling of lease interests if the various lease holders did not come to terms with each other.

[20] Ely, 51 *Harvard Law Review* 1244; Sir John Cadman, *op. cit.*, p. 2.

[21] Gibson, *op. cit.*, p. 539. Such procedure was followed in the development of the Kirkuk field in Irak. Gibson suggests that the following information be obtained before commercial withdrawal: Size and shape of reservoir, position of gas-oil level, position of oil-water level, characteristics of oil bearing information, and physical properties of crude.

Basis for sharing royalties.—The greatest difficulty in setting up a scheme of unit operation is the determination of a basis for sharing the net receipts. Certainly the lessees' royalties will not depend upon well locations. In general, three bases have been suggested: oil in place, acreage, or some combination of these two. Equity would seem to dictate that a property owner's royalty depend upon the oil in place in the section of the reservoir under his land. Although some doubt the feasibility of arriving at satisfactory estimates of oil in place, informed opinion is that the contents of parts of the reservoir can be so determined during the course of production.[23] Though courts have been slow to accept engineering estimates of recoverable reserves from a common reservoir. the Supreme Court of Texas in *Brown* vs. *Humble Oil and Refining Company*[24] has made express reference to the fact that while these estimates may contain error, they are nevertheless the basis on which the various units of the oil and gas industry risk their money, and that, therefore, these estimates may with justification serve as the basis for allocating production.[25] Basing royalties upon estimates of oil in place does not necessarily mean that the owner will receive no return after production stops on his or adjoining properties.[26] The production methods adopted by the pool management probably would result in oil and gas migrating from one part of the pool to another. Furthermore, unit operation would provide for the sharing of crude oil receipts among owners whose property lay entirely over the gas cap or for some basis of equating the oil and gas in the same reservoir.

In small fields or within unit sections of an oil and gas-bearing structure, royalty rights might be justly based upon acreage. Thus, in well-spacing orders for incorporated communities. adjoining property owners who were forbidden the right to wells were allowed to share on an acreage basis in the oil royalties obtained from the wells allowed within the block or well-spacing unit.[27] Moreover, dividing royalties within well-spacing units according to acreage has been applied to rural areas in Oklahoma and may be used in Arkansas, New Mexico, and Louisiana.[28] An acreage basis of allocating receipts for an entire structure has been proposed by geologists.[29]

As another alternative, royalties might be shared on the basis of oil in place modified by an acreage factor. Thus, O. E. Kiessling, of the United States Bureau of Mines, proposed that royalties be allocated one-third in proportion to acreage and two-thirds in proportion to oil in place as indicated by potential recoverable content.[30] Alexander Sachs and Joseph E. Pogue recently suggested that allocation be based upon a formula containing both potential production of the lease and acreage of the lease.[31] The State proration regulations in Arkansas provide that allowable production be based half on acreage and half on reservoir pressure as indicated by changes in bottom hole pressures.[32] Another rule based half on acreage and half on potential has been adopted in many instances by the Texas Railroad Commission.[33]

One of the most difficult problems in connection with the sharing of royalties under a unit operation arrangement is the rewarding of owners of the gas cap or of lands located above the edge of the water drive (the oil-water contact line). Although this problem is not solved, it has been suggested that the State might require the postponement of production until the energy in the gas cap is measured and until a plan is devised for compensating the owners by their sharing in the production from the other districts in the field on some proportionate basis.[34] Similar arrangements might be made for spreading over the field the expense of reinjecting excess water produced by edge-water districts.[35]

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[22] *Ibid.*

[23] J. R. Parten, *Oil Weekly*, December 18, 1931, pp. 69–71, holds that engineers cannot determine oil in place; the opposing view is expressed by Earl Oliver, *op. cit.*, p. 142. Moreover, in 1931, 16 engineers who were considered qualified to express an opinion on determining an "extractable acreage content" reported in answer to a questionnaire from Oliver that methods could be devised to measure the relative content of adjacent tracts in a common pool. See Earl Oliver, "Stabilizing Influences for the Petroleum Industry," *A. I. M. M. E., Pet. Dev. Tech., 1932*, pp. 22–37; also quoted in *Petroleum Investigation, 1934*, p. 1271.

[24] 126 Tex. 296, 83 S. W. (2d) 935 (1935).

[25] Oliver has described the engineering appraisal method of estimating recoverable acreage content as being based upon information "on the reservoir and its contents, such as thickness and extent of producing sand, its porosity, permeability, and saturation; pressure in the reservoir; potential capacity of wells; and many other factors that must be weighed and evaluated in formulating estimates." Oliver, *A. I. M. M. E., Pet. Dev. Tech., 1937*, p. 142.

[26] This thesis is advanced by E. H. Griswold, "Oil and Gas Content As Standard of Land-Owner's Rights," *A. I. M. M. E., Pet. Dev. Tech., 1933*, pp. 40–44.

[27] Such units were set up in Oxford, Kans., by the city council; in South Houston, Tex., by the Texas Railroad Commission; and in Oklahoma City, by the Oklahoma Corporation Commission.

[28] The Oklahoma statute requires that "in the event a producing well or wells is completed upon a unit where there are two or more separately owned tracts any royalty owner or group of royalty owners, holding the royalty interest under a separately owned tract, shall share in one eighth of all the production from the well or wells drilled within the unit in the proportion that the acreage of their separately owned tract bears to the entire acreage of the unit." S. L. 1935. 52 Okla. St. Ann, par. 87, subd. (c). This law was upheld in *Patterson* vs. *Stanolind Oil and Gas Company*, 77 Pacific (2d) 83. See also Ely, 51 *Harvard Law Review* 1235.

[29] See O. E. Kiessling. "Cooperative Development of Oil Pools," *A. I. M. M. E., Pet. Dev. Tech., 1927*, p. 781; and Fay L. Wright, "Some Economic Aspects of the Community Oil Lease." *A. I. M. M. E., Pet. Dev. Tech., 1925*, pp. 769–778.

[30] Kiessling, *op. cit.*, p. 780.

[31] "Internal Problems of Proration in Oil Conservation," *Transcript of Proceedings of the Interstate Oil Compact Commission*, July 29, 1938, pp. 29–30.

[32] Report of A. M. Crowell, Chief Conservation Agent, State of Arkansas, to Dr. George C. Brenner, Chairman, Executive Committee, State Planning Board, Little Rock, Arkansas (Sept. 1, 1938), for submission to the National Resources Committee.

[33] For example, the new Sun field in Starr County. *Journal of Commerce*, Nov. 28, 1938, p. 23.

[34] Cf. Ely, 51 Harvard Law Review 1239.

Probably the importance of the gas cap in most structures has been overemphasized. Usually the proportion of energy in free gas is small in comparison with total reservoir energy. Ben E. Lindsly has pointed out that "the exaggerated idea of this gas cap energy held by many probably is caused by the fact that the energy in the gas cap is continually replenished by gas energy which comes from gas liberated from solution in the oil. To allow the gas cap area all of the gas and gas energy which it originally contained and all of the gas and gas energy which it draws from other parts of the property would be rank injustice to the owners of the oil portions of the structure."

Although the evaluation of the gas cap in relation to the oil-bearing parts of the structure is not a simple problem, surely a satisfactory method of equating the values of free gas and oil in the reservoir could be found.[36] Ben E. Lindsly has proposed that each "tract be credited for both the amount of energy in foot pounds and the amount of oil that it is capable of contributing to the common pool. A satisfactory formula could be worked out for converting energy credits into oil credits.[36a]

The solution of this problem might include legislation by the State providing that the reservoir energy should be common property of all owners of mineral rights in a pool.[37] Or the State through the legislature or courts, as a police measure, might require the deferring of the use of free gas at the top of the pool until all the recoverable crude oil has been obtained, at which time the owners of the gas cap would share in the royalties from the production according to the original location of the gas.[38] The arrangements necessary to solve this problem of rewarding the owners of the gas cap under unit operation, which would necessitate the postponement of production from the gas cap, are matters for State legislation. Already the police power of the State has been held to cover the regulation or restriction of production with a view to preventing unreasonable and wasteful production, as well as injury to others.[39] It could probably be extended to require complete postponement of use or joint sharing among owners of oil and of gas in the same oil and gas pool.

Other difficulties in unit operation.—A system of unit operation can be introduced into an old oil or gas field, but its effect cannot be made retroactive. It can apparently apply, however, to the operation of existing wells, as well as to any extensions of the field.[40] Under compulsory unit operation State regulatory commissions might well require the closing of some wells when the plan is set up in fairly new fields and the sharing of royalties from the remaining producing wells among property owners in the pool unit.

Some have claimed unit operation might constitute an undue granting of monopoly power to a few companies with a consequent restriction of production and raising of price of crude oil or natural gas.[41] This might in some regions become a serious possibility, although no single operator or combination of operators would control a much larger percentage of total output than is already the case.[42] In any event, unit operation should involve continued Government inspection and regulation. During the early operation of unitization on large structures there undoubtedly would be many disputes which would lead to considerable litigation over the determination of oil in place and the extent of drainage.[43] Under a compulsory system, however, the litigation would probably be less than under a voluntary system, where it might be to the interests of certain individuals to break the unit agreement.[44]

Major advantages of unit operation.—Unit operation facilitates the general adoption in an oil field of the best current engineering and production practices. It does not, of course, guarantee these practices, since they are partly a result of effective State regulation and of intelligent local management. Preliminary exploration can discover the extent and nature of the pool, and continued measurements can give a guide to the most effective production procedure. Unit operation, for example, will allow production at various rates, the use of wells for somewhat different purposes, the spacing of wells in relationship to the contour of the pool, the abandonment or shutting in of wells as water or gas ratios become excessive, and the adoption of pressure maintenance or other secondary methods of recovery. Superior engineering procedures applied under unit operation make possible the conservation of reservoir energy and maximum recovery of oil. In addition, a greater percentage of the lighter fractions of the crude can be recovered by keeping all the dissolved gas in solution.[45] Of course, production control for the purpose of maximum recovery requires rates of operation lower than occur in competitive production. Aside from reducing underground waste, less speed means less waste in accidents and in losses of oil at the surface through fires or through wells getting out of control.[46]

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[35] "The suggestion has been made in the East Texas field that a sanitary district be formed, to dispose of water produced by oil wells by means of reinjection." *Ibid.*

[36] Some have held that this cannot be done satisfactorily. For example, see the statement of J. O. Lewis, formerly of the U. S. Bureau of Mines and at that time of Dunn and Lewis, Tulsa, Okla., before the forum on reservoir energy, *A. I. M. M. E., Pet. Dev. Tech., 1933,* p. 23. On the other hand, Ben E. Lindsly, senior petroleum engineer of the U. S. Bureau of Mines, has held that a fair appraisal of a tract for unit operation was feasible. *Ibid.,* p. 24. See also a statement of J. A. Veasey, general counsel of the Carter Oil Co. *Ibid.,* p. 26.

[36a] Correspondence, February 1939.

[37] See suggestion of J. P. Umpleby, *ibid.,* p. 23.

[38] It has been suggested that the *Cedar Rust* case furnished a precedent which would allow the State to condemn the use of free gas at the top of the structure if the production of that gas led to waste of the more valuable crude. See statement of J. A. Veasey, *op. cit.,* p. 26; and comment by W. S. Farish, at that time president, Humble Oil Refining Co., p. 27.

[39] See discussion by W. P. Z. German, general attorney, Skelly Oil Co., *op. cit.,* p. 25.

[40] This would seem to follow from the *Patterson* vs. *Stanolind Oil and Gas Company* case, where a system of well spacing was introduced in an operating field but where the pooling or royalties among different landowners in the same tract dated only from the well-spacing order of the State commission. 77 Pacific (2d) 83.

[41] For example, the statement by J. R. Parten, *op. cit.,* pp. 69–71.

[42] Hines has stated that a real unit of production is usually small and that most unit pool plans would include numerous landowners, royalty owners, and operators. Hines, *op. cit.,* p. 9.

[43] Parten, *loc. cit.*

[44] See discussion by E. H. Griswold, *op. cit.,* p. 43.

Thus unit operation can lead to the reduction of production costs by eliminating unnecessary drilling, by maximum utilization of reservoir energy for lifting oil to the surface, by avoiding a high initial peak in capital investment and surface-plant equipment, which is ordinarily in use only a short time, by avoiding a similar peak demand for auxiliary services, such as roads, water supply, and staff accommodation, and by offering possibilities for research and constant checking on production methods.[47] Savings in capital investment in comparison with the usual competitive development of a field would appear to be enormous. It was estimated in May 1930 that "if the Oklahoma City field could have been fully unitized, development costing $3,000,000 could have produced as much income to date as the $32,500,000 now in completed wells, to say nothing of the $37,500,000 in the course of being spent." [48]

In addition effective unit operation plans must be based on an extensive knowledge of underground reserves. Indeed one of the distinctive features of unit operation is the careful determination of the pool limits. By greater preliminary exploration, unit operation tends to increase known reserves. This substitution of greater proven reserves for the usual flush production results in savings of storage tanks, the avoiding of evaporation losses, and in considerable measure the elimination of fire risks. Moreover, excessive products may be returned to the reservoir.[49] Unit operation possesses a further advantage in that it sets up an arrangement by which production can be easily and scientifically restricted.[50] Production quotas can be allocated among pools, and the question of the production of the pool's allowed amount can be determined from the viewpoint of efficiency by the pool's management. It would presumably never be necessary to unduly restrict the production of any well because the drilling of an excessive number of holes, such as occurs under flush production, would be avoided.

For the individual property owner unit operation is desirable because it facilitates remuneration according to a more acurate determination of oil in place and leads to a greater recovery of this oil and at lower costs. Thus, in the long run, his net return should almost always be greater than under a system of competitive drilling.[51]

Extent of adoption.—Unit operation is invariably practiced in those countries where mineral rights are the property of the State or where concessions covering large areas are given to single operating companies. Thus, in Soviet Russia, unit operation is practiced by State trusts, and in the major fields of Iran (Persia) and Iraq unit operation is practiced by the foreign oil companies which hold concessions in these two countries. Unit operation is regarded so highly by British oil companies that they were partially responsible for the enactment in Great Britain of a law whereby unit development may be enforced in the event petroleum is discovered in commercial quantities.[52] Unit operation is also practiced in parts of Venezuela, where foreign oil companies hold large contiguous blocks of leases.

Voluntary unit operation has been practiced in the United States for many years and particularly since about 1927, when a period of overproduction stimulated interest in unit control as a stabilization device. Perhaps as many as 30 pools or sections of pools are operated under some kind of unit management at the present time, but these make up a very small percentage of the total production.[53]

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[45] Gibson, *op. cit.*, p. 537. "In order to keep losses due to capillarity and adhesion to a minimum, therefore, it is necessary to maintain a surface tension of the crude at as low a value as possible; and this can only be achieved by keeping all dissolved gas in solution.

"Only in the most permeable formations can a reasonable production rate be attained without assistance from some other source of energy, but by keeping all dissolved gases in solution the viscosity of the oil remains at its lowest possible value and a minimum of assistance will be required."

[46] Cf. Gibson, *op. cit.*, p. 536.

[47] Sir John Cadman, *op. cit.*, pp. 2–3; Gibson, *op. cit.*, p. 536; *Oil and Gas Journal*, July 7, 1938, p. 70.

[48] A statement by Mr. W. N. Davis, vice president of the Phillips Petroleum Company and vice president of the American Petroleum Institute, as quoted in C. E. Fraser and G. F. Doriot, *Analyzing Our Industries* (New York, 1932), p. 417, n. 2. For the advantages of coordinated development in the Dominguez Hills field and the Belvedere Gardens in southern California, see Wright, *op. cit.*, pp. 769–778, and Federal Oil Conservation Board, *Report I to the President of the United States, 1926*, pp. 18–19.

[49] Thus, from 1929 to 1936 the Anglo-Iranian Oil Company returned a total of approximately 30 million barrels of products to the Masjid-i-Sulaiman reservoir. Such products are blended at the surface before return to the reservoir. Cadman, *op. cit.*, pp. 5–6. A demonstration in Tulsa County, Okla., was described in the *New York Times* (sec. 3, p. 1), July 7, 1938.

[50] Indeed, unit operation was first proposed as a means of stabilizing production; see Hines, *op. cit.*, p. 7. During the period of flush production in East Texas in 1931–32, unit operation was again advocated primarily for this purpose. Fraser and Doriot, *op. cit.*, pp. 418–19. The plan has also been used for this purpose in gas fields. *Oil and Gas Journal*, May 19, 1938, p. 38.

[51] Henry M. Bates, "Some Constitutional Aspects of the Oil Problem," *A. I. M. M. E., Pet. Dev. Tech., 1935*, p. 199; and L. G. E. Bignell, "Problems from Readers," *Oil and Gas Journal*, July 7, 1938, p. 70.

[52] Gibson, *op. cit.*, p. 536.

[53] About fifteen pools in the United States were operated as units in 1927. *Ibid.*

Many of the more important unit schemes in the United States involve Federal land. One of the first major legislative moves in the direction of unit operation in the United States was the enactment by Congress of a law applying to lands belonging to the United States.[54] This 1930 act provided for only voluntary unitization and was experimental in character. Legislation of a permanent character relating to voluntary unit operation was passed on March 4, 1931.[55] An act of August 21, 1935, provided for compulsory unitization; under this act the "Secretary of the Interior, for the purpose of more properly conserving the oil or gas resources of any area, field, or pool, may require that leases hereafter issued under any section of this Act be conditioned upon an agreement by the lessee to operate, under such reasonable cooperative or unit plan for the development and operation of any such area, field, or pool as said Secretary may determine to be practicable and necessary or advisable, which plan shall adequately protect the rights of all parties in interest, including the United States." [55a]

Under the Acts of 1930 and 1931 the Secretary of the Interior approved several unit plans involving Government lands. Unitization was approved where the productive area of the field could be delimited.[56] The most important of these plans were those in the Kettleman Hills field—at the North Dome and at the Middle Dome. Most of these unit plans have included considerable private land.[57] Despite the noninclusion of important minority interests, the Kettleman Hills plans undoubtedly have restricted waste. Thus in the North Dome Association, which worked in close cooperation with the Standard Oil Co. of California, and had direct or indirect control over 95 percent of the land under structure, wastage of natural gas was reduced from 109 billion cubic feet in 1930 to 3 billion cubic feet in 1933. In addition to the savings in natural gas, the ultimate recovery of oil has been greatly increased.[58] Unit operation of new oil fields presumably might have been required under the code of fair competition for the petroleum industry, since that code provided, among other things, for the operation of newly discovered fields in accordance with the plan approved by the President.[59] In no instance, however, did the President require new fields to be operated under a system of unitization.

In a very restricted manner unit operation has been adopted and approved by the laws and regulations of Arkansas, Oklahoma, New Mexico, and Louisiana, in the sense that pooling of mineral rights within well-spacing units can be required by the regulatory authorities of the States. The drilling district or proration unit seems to be a step in the direction of compulsory unit operation of the entire pool.[60] All that seems to be necessary is that the State require that the wells in adjoining drilling districts be operated according to standard regulations and that some method be found of compensating the owners of the gas cap.

Widely recommended.—Unit operation of oil and gas pools has been widely recommended by geologists and engineers,[61] oil producers,[62] lawyers,[63] economists,[64] and

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[54] The act of July 3, 1930 (46 Stat. 1007), amending sections 17 and 27 of the act of February 25, 1920 (41 Stat. 437), commonly known as the "Mineral Leasing Act." Hines, *op. cit.*, pp. 21–22.

[55] The act of March 4, 1931 (46 Stat. 1523), which further amended section 17 and 27 of the Mineral Leasing Act. Hines, *op. cit.*, p. 22.

[55a] The Act of August 21, 1935 (49 Stat. 674), Section 17.

[56] These plans have been approved where the field is delimited by a contour line on top of the productive sands; where the productive area is limited to the portion of the field lying above a stated contour line, including 10-acre tracts through which the contour passes; and where the productive area is defined as that lying between 2 contour lines, the inner line being the boundary of the irreducible unitized area and the outer line being the boundary of the maximum possible productive limits of the field. Hines, *op. cit.*, p. 23.

[57] R. E. Collom and C. P. Watson, "Review of Developments at Kettleman Hills," *A. I. M. M. E., Pet. Dev. Tech., 1937,* pp. 195–213; Hines, *op. cit.*, pp. 24–29; and, concerning the North Dome plan, see also *Petroleum Investigation, 1934,* pp. 1260–66.

[58] Federal Oil Conservation Board, *Report V, 1932,* p. 50; Miller and Lindsly in *Petroleum Investigation, 1934,* p. 1266; *Minerals Yearbook, 1935,* p. 800.

[59] National Recovery Act, *Code of Fair Competition for the Petroleum Industry,* Article III, Section 7, p. 10.

[60] Ely, 51 *Harvard Law Review* 1235. In the laws providing for unitization of tracts within proration units, there is a difference among the states in degree of enforcement. The Oklahoma law forces the majority interest to allow the minority interest to share the cost of a well and the production therefrom. The laws of New Mexico and Louisiana authorize the regulatory commission to require the pooling of tracts if allowing a well on a small tract would result in waste; but the majority interest can refuse to pool in which case the small-tract owner is granted a well. The strongest provision is in the Arkansas law which states that the commission shall require owners of separate tracts within a drilling unit to integrate their interests. See Session laws of these States.

[61] In 1929 the petroleum division of the American Institute of Mining and Metallurgical Engineers set up a committee to study unit operation. The following year this committee approved of unitization as a means of avoiding waste as well as adjusting production to demand and further as an opportunity for applying improved production methods; see Miller and Lindsly, *op. cit.*, p. 1251, and *A. I. M. M. E., Pet. Dev. Tech., 1930,* p. 11. An investigation in 1931 by Earl Oliver, chairman of the A. I. M. M. E. Unit Operation Committee, also indicated that engineers approved of unit operation. See *A. I. M. M. E., Pet. Dev. Tech., 1932,* pp. 22–37, and also *Petroleum Investigation,* pp. 1271–1272. Despite their approval of unit operation engineers have recognized the difficulties in its adoption, particularly on a voluntary basis. See Leonard Logan, "Stabilization of the Petroleum Industry," *A. I. M. M. E., Pet. Dev. Tech., 1931,* pp. 618, 619, 624, and also J. P. Umpleby, "Production Engineering in 1927," *A. I. M. M. E., Pet. Dev. Tech., 1928,* p. 20. Some geologists held that in most pools unit operation would not materially increase the crude oil which could be lifted by the reservoir energy and, moreover, that it would not lead to any materially greater ultimate recovery. Much depends upon reservoir conditions and the size and permeability of the strata.

[62] Among businessmen the strongest recommendation of unit operation was that made by Henry L. Doherty in 1924. See *A. I. M. M. E., Pet. Dev. Tech., 1925,* p. 7; also Logan, *op. cit.*, p. 140; Federal Oil Conservation Board, *Public Hearing,* May 1926. Mr. Doherty recommended the voluntary pooling of leasing interests. Judge C. B. Ames, chairman of the board of the Texas Co., recommended unit operation in 1930, but pointed out that the system would be very difficult to introduce and that in his opinion it could not be compulsory; C. B. Ames, "What's the Matter With the Petroleum Industry," American Petroleum Institute, *Production Bulletin 206,* 1930, p. 94; also quoted in *Petroleum Investigation,* p. 1251. A. L. Beaty, of the Texas Co., had proposed a voluntary system of unit operation a few years before; see William J. Kemnitzer, *Rebirth of Monopoly,* p. 126. An English authority, C. A. P. Southwell, declared that the only way of achieving maximum ultimate recovery at minimum cost was under a system of unit control whereby production was held back until complete scientific data indicated the most desirable production rates; see "Scientific Unit Control," *Proceed-*

Government regulatory bodies [65] and, in most instances, those individuals concerned with the conservation of oil and gas and the operation of the industry have recommended compulsory unitization.

Among petroleum geologists and engineers, perhaps one of the most significant recommendations of unit operation is that of H. C. Miller and Ben E. Lindsly, of the United States Bureau of Mines. In their opinion, unit operation presents no insuperable problems.[66]

Among oil producers, one of the strongest endorsements of unit operation was that by C. H. Lieb, president of Carter Oil Co., in an address in May 1936 before the midcontinent section of the American Institute of Mining and Metallurgical Engineers, in which Mr. Lieb advocated wider well spacing and pressure maintenance, as well as unitization; or modification of the rule of capture so as to permit "and wherever possible, * * * to compel" the foregoing practices.[67]

Accomplishments.—The greatest achievements of unit operation are those in Persia and Iraq. The fields in those countries have produced a much larger percentage of their oils by natural means—that is, by use of reservoir energy—and have been characterized by costs considerably less than those in the United States.[68]

Oliver and Umpleby further state that the greater part of foreign oil is produced from large blocks with the competitive feature either absent or very materially reduced, whereas most American oil is produced under competitive conditions of waste and high cost.[69] The great advantage of unit control is illustrated by the operation of the Anglo-Iranian Oil Co., of the Masjid-i-Sulaiman field in Persia. From February 1929 to the end of 1932, no well in that field "has ceased natural flow on account of declining pressure or of diminished drainage from the reservoir rock. No well has been taken off

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ings of World Petroleum Congress of 1933, Geological and Production Sections, pp. 304–309; also Watkins, *op. cit.,* p. 140. In 1931 J. Edgar Pew of the Sun Oil Co., in addressing the American Petroleum Institute said, "I do believe that the best method of operating an oil field can only be reached through some kind of unit, or cooperative, operation. I believe that 75 to 90 percent of the industry believes the same." "Time is Ripe for Unitization," *Oil and Gas Journal,* November 12, 1931, p. 38. Unit operation is favored by H. M. Stalcup of the Skelly Oil Co., *Oil and Gas Journal,* May 19, 1938; and also by L. J. Willien, H. E. Bates, G. M. Davidson, and R. M. Bussard of the American Gas Association, "Organization of the Production, Transportation, and Distribution of Natural Gas and Manufactured Gas by Utilities," *Third World Power Conference,* sec. 2, Paper 6, p. 32.

[63] Compulsory unit operation has been approved by Henry M. Bates, Dean of Michigan Law School, *op. cit.,* pp. 199–201; by Donald H. Ford, "Controlling Oil Production," 30 *Michigan Law Review* 1170 (1932); and Charles G. Haglund, "The New Conservation Movement with Respect to Petroleum and Natural Gas," 22 *Kentucky Law Journal* 1934, pp. 564–565. Haglund points out that unit operation could not be achieved by voluntary agreements alone where there are a great many surface owners. He points out that "legislation would be necessary to compel joinder in unit operation when the majority or some greater proportion of the surface owners desired to so operate the pool." Ford further points out that unit operation does not require the merger of land titles, and such merger probably could not be compelled; yet "if the petroleum engineers and geologists can determine the surface owners' share of the oil in the pool * * * to the satisfaction of the courts and legislators, there would seem to be no reason why the law cannot make the surface owners tenants in common of the oil in the pool and thus recognize such correlative rights of the owners." In 1928 a committee of the section of mineral law of the American Bar Association recommended, in connection with the unit operation of oil pools, that "if the police power of the oil-producing States is to be invoked, it must be in relation to a plan for the compulsory cooperative development and operation of oil pools." Federal Oil Conservation Board, *Report III to the President of the United States, 1929,* p. 34. By "compulsory cooperative development," this committee apparently meant that the State could force a minority of operators in a pool to take part in a plan for cooperative development and operation, if the majority of the operators in the pool had agreed in writing upon a plan and if they had attempted to secure the adherence of all interested operators. See section 4 of a proposed act to provide for cooperative development and operation, *ibid.,* p. 45. This recommendation that the State police power be used to force a minority of interests into agreeing to a cooperative unit scheme was also given by Haglund, *op. cit.;* Haglund, however, appears to go somewhat farther in advocating the use of the State police power in setting up unit operation. Legal bases for compulsory unit operation have already been established, according to Henry M. Gray of Jameson, Gray, and Gilmer, "Need Extension of Conservation Laws," *Oil and Gas Journal,* July 23, 1931, pp. 24 and 98. Robert E. Hardwicke also approved of unit operation; see "Legal Aspects of Gas Conservation," *Oil and Gas Journal,* June 25, 1931, p. 126. Also strongly in favor of operating each oil field as a unit are Northcutt Ely, "Governmental Regulation of Oil Production," *A. I. M. M. E., Pet. Dev. Tech., 1937,* p. 160; and W. P. Z. German of Skelly Oil Co., "Legal Aspects of Unitized Operations," *Oil and Gas Journal,* November 12, 1931, p. 34.

[64] Compulsory unit operation has been recommended by George W. Stocking, "Stabilization of the Oil Industry; Its Economic and Legal Aspects," *American Economic Review,* Supplement, March 1933, p. 70; by C. E. Fraser and G. F. Doriot, *op. cit.,* p. 418; and by Joseph E. Pogue, "Economic Aspects of Unit Operation of Oil Pools," *A. I. M. M. E., Pet. Dev. Tech., 1931,* pp. 93–95, and "The Economic Structure of the American Petroleum Industry," *Third World Power Conference,* sec. 2, Paper 5, p. 6; and also *Petroleum Investigation, 1934,* p. 1274. Voluntary unit operation has also been recommended by O. E. Kiessling, *A. I. M. M. E., Pet. Dev. Tech., 1927,* pp. 779–781, and appears to be approved of by Myron W. Watkins, *op. cit.,* p. 140.

[65] Unit operation on a voluntary basis was many times recommended by the Federal Oil Conservation Board; see *Report I to the President of the United States, 1926,* pp. 15–16; *Report III to the President of the United States, 1929,* p. 4; *Report IV to the President of the United States, 1930,* pp. 17–24; and *Report V to the President of the United States, 1932,* p. 20. In the last report the board stated that "a race for capture militates against scientific spacing of wells, efficient rates of production, and against maximum recovery. The correction lies in coordination of operation by the various owners, either through agreement or because of exercise of the sovereign's authority." Secretary of Commerce Lamont in an address before the American Petroleum Institute, November 12, 1931, proposed uniform state laws authorizing unit operation and broad regulatory powers for enforcing maximum recovery methods, *New York Times,* Nov. 12, 1931, p. 20. In addition some State authorities have recommended compulsory unit operation. For example, see report by A. M. Crowell, chief conservation agent of Arkansas, to the Arkansas State Planning Board, September 1, 1938. The Kansas State Planning Board has recommended compulsory unit operation at the discretion of the Kansas State Corporation Commission; see Kansas State Planning Board, "Experience of Kansas under Petroleum Production; Control and Conservation Measures" (Nov. 1938), pp. 11–12, in a report submitted to the National Resources Committee. Nathan R. Margold, then of the Petroleum Administrative Board, held that Congress had the power to compel scientific development of an oil field; *Petroleum Investigation, 1934,* p. 480. John W. Frey and E. B. Swanson of the Petroleum Conservation Division of the U. S. Department of the Interior, have pointed out that unit operation does not necessarily mean good operation; Petroleum Administrative Board, *Operation of New Pool Plans of Orderly Development under the Code of Fair Competition for the Petroleum Industry,* 1936, p. 38. They are assuming that unit operation might not be accompanied by the best engineering procedures. Under adequate regulation, however, their assumption would be invalid.

[66] *Petroleum Investigation, 1934,* pp. 1271, 1306.

[67] Pogue, *Third World Power Conference, op. cit.,* p. 20 n.

[68] Earl Oliver and J. P. Umpleby, "Principles of Unit Operation," *A. I. M. M. E., Pet. Dev. Tech., 1930,* p. 105. Also Miller and Lindsly, *Petroleum Investigation, 1934,* pp. 1254–1255.

[69] *Ibid.*

production on account of edge-water encroachment, nor indeed has edge water been produced in any production well. A certain number of wells have gone to gas and been closed in, but this is strictly in accordance with our system of operation: the dates on which such wells have gone to gas have corresponded closely with estimates existing 4 years ago, and replacement wells have, where necessary, been methodically completed in advance of these dates. The pressure in the gas dome of the Masjid-i-Sulaiman field has dropped only 5 pounds per square inch—approximately 1 percent—during the past 4 years, although a production of nearly 20,000,000 tons has been drawn from the field during that period."[70]

Sir John Cadman has attributed these achievements largely to unit operation, supported by adequate engineering standards.

The average production per well in the Kirkuk field in Iraq and in the Haft Kell field in Iran (Persia) in 1935 was nearly 50 times the average production per well during conditions of peak production in 1933. More than 20,000 wells in east Texas were used to obtain a production of 205 million barrels in 1933, whereas in the Kirkuk field 45 wells were sufficient to produce 27 million barrels of oil in 1935, and in the Haft Kell field 40 wells were sufficient to produce 27 million barrels in the same year.[71]

As already indicated, significant achievements of unit operation in the United States have been in the Kettleman Hills field in the San Joaquin Valley in California, in the Belvedere Gardens and Dominguez Hills fields in southern California, in the Van, Yates, and Sugarland fields in Texas, the Hobbs field in New Mexico, and the South Burbank and other Osage County fields in Oklahoma. The difference in costs of production between fields developed cooperatively, and those developed competitively is impressive.[72]

Kettleman Hills is not an example of thoroughly successful unit operation, mainly because unitization was not complete. The small noncooperative outside interests caused much unnecessary waste; practices existed which would not have occurred under full unit operation. On the other hand, partial unitization made it possible to avoid many wasteful methods. It was not by accident that the lowest operating costs among California fields, 1931 to 1934, were those for Kettleman Hills and the next lowest, those for Dominguez.[72a]

Required Minimum Engineering Standards

The possibilities of achieving conservation by Federal and State regulation of the oil and gas industry depend upon the establishment and enforcement of the best current engineering procedures. These have been variously referred to in the previous chapters of this section. It should be pointed out here that if regulation is to be continued even in part on the basis of production control, important gains in conservation may not be achieved unless proration efforts include improved rules and regulations concerning the ways in which oil and gas fields are to be operated. Production restriction creates the opportunity for conservation in that it tends to raise the market price of these natural resources. Minimum engineering standards are necessary to see that conservation is actually achieved. Indeed, regulatory authorities might vary to some degree the standards of efficiency of operation in recovery with price.

Although minimum engineering standards are a necessary accompaniment of unit operation, if full conservation is to be achieved, minimum engineering standards themselves, in the absence of laws and regulations providing for compulsory unit operation, can make a considerable improvement in the relative recovery of natural resources. Heretofore, most regulations covering field operation have been those established and enforced by State regulatory bodies. Among States one of the most complete sets of rules and regulations governing production and conservation of oil and gas is that established by the Oil Conservation Commission of New Mexico under the State laws.[73] Arkansas and Louisiana also have thoroughgoing conservation laws, modeled in large part after the New Mexico law. Unfortunately, regulatory practice in New Mexico has not always been as exemplary as its laws. On the other hand, despite inadequate conservation legislation until recently, Arkansas regulation has been more ideal.

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[70] Sir John Cadman, "Persia," *A. I. M. M. E., Pet. Dev. Tech., 1933*, pp. 399–400.

[71] Sir John Cadman, "Conservation of Petroleum," *Third World Power Conference*, sec. 4, Paper 12, p. 3; *Minerals Yearbook, 1937*, p. 1022.

[72] *Petroleum Investigation, 1934*, pp. 1260–66; Federal Oil Conservation Board, *Report I to the President of the United States*, pp. 16–19; *Oil and Gas Journal*, July 7, 1938, p. 24; and H. E. Rorschach & E. G. Dahlgren, "Petroleum Development in Oklahoma in 1936," *A. I. M. M. E., Pet. Dev. Tech., 1937*, pp. 440–41. For production costs see a study by the Standard Oil Co., "Comparative Costs of Cooperative Development of Pools," *Oil and Gas Journal*, April 6, 1933, p. 78.

[72a] The operating expense per barrel of company-interest oil in 1934 was $0.063 for Kettleman Hills, $0.094 for Dominguez, and $2.08 for all California. Petroleum Administrative Board, *Report on the Cost of Producing Crude Petroleum*, Dec. 1935, pp. 114–15.

[73] State of New Mexico Oil Conservation Commission, Circular No. 1, *Oil and Gas Conservation Law and General Rules and Regulations for the Conservation of Oil and Gas in New Mexico*, August 12, 1935, reprinted February 1, 1937. The law providing for the conservation of oil and gas in New Mexico is Session Laws of New Mexico, 1935, chapter 72, and the general rules governing the conservation of oil and gas in that State is known as Order No. 4 of the Oil Conservation Commission of New Mexico. In addition, the New Mexico Oil Commission has issued special rules and regulations applying to particular fields. See for example, Order No. 7, *Special Rules and Regulations for the Hobbs, Jal, Cooper, Eunice, and Monument Fields, Lea County, New Mexico*, Circular No. 2, September 3, 1935, later modified by Order No. 52, *Special Rules and Regulations for the Lea County Fields, New Mexico*, Circular No. 3, February 1, 1937.

These engineering regulations should cover the whole sphere of activity in the oil and gas industry from exploration and drilling on through the final abandonment of the well.[74]

In addition, under its powers to regulate interstate commerce and to provide for the national defense, the Federal Government might require that in all States oil and gas be produced in compliance with certain defined basic rules of operation.

The cause of conservation can be doubly served by well-spacing regulations which vary with the nature of the reservoir. By restricting drilling, especially in proven areas, ultimate recovery can be increased, and at the same time great savings in capital investment can be made. In addition, as already indicated, well-spacing regulations are a means of restricting production. The old argument in the industry, whether wells should be widely or closely spaced, has been largely resolved into a geologic problem depending upon the porosity, permeability, and gas pressure in the reservoir sands.[75] Although there may be some differences of opinion as to correct drilling density, even where wells are spaced with reference to the oil structure and produced at a controlled rate, there is little dispute as to the adverse result on reservoir pressure where excessive drilling is at random without regard to reservoir conditions.[76]

Whenever reservoir conditions are incompletely known, wider well spacing is to be preferred. A later generation of wells may appear advisable after collection of more complete information, if, for example, it is found that the strata are fine-grained and of low permeability.[77] Regulation of drilling and casing practice may also lead to protection of oil- or gas-bearing strata, as well as of sources of water which are used for human consumption or for irrigation.

Regulation of the rate of flow of oil and gas should be based in part upon the control of gas-oil ratios if maximum recovery is to be achieved. Theoretically, the rate of flow may be too slow to provide maximum recovery, particularly of the more valuable fractions of the crude petroleum; but, as a rule, a low rate is to be preferred to a high rate. A controlled and usually low rate of gas production will lead to the production of a larger percentage of the oil by means of the reservoir energy. The viscosity of the oil will be better maintained, and less of the more volatile fractions will be lost. If production is too rapid, the gas in the crude is given off, and much of the crude can never be recovered even by methods of repressuring.[77a] Regulation of rate of flow in a unitized area would aim at a constancy throughout the field of fall in gas-oil level and rise of oil-water level in order that the greatest measure of drainage be secured. Thus, in Persia, in order to conserve gas pressure, it has been the practice to plug those wells which by reason of descending gas-oil level show gas-oil ratios increasing above the normal.[78] Gas-oil ratios should always be determined by reference to reservoir conditions with the aim of achieving maximum ultimate production of both oil and gas. If unit operation is not feasible and the regulation of the industry must continue primarily on the basis of proration, well allowables should be determined by reference to maximum ultimate recovery and not according to marketing conditions based upon certain minimum production for existing wells. If the maximum allowable for a State is so low that the rates of operation are far under the optimum, it would probably be better to produce in excess of the allowable, even though the price of oil drops somewhat. From the standpoint of recovery the problem would consist of a comparison between the losses in excess storage and the losses owing to too low a rate of production.

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[74] For example, the New Mexico rules cover the following subjects: Sign on wells, general spacing rules, well record, deviation tests, pit for shale drill cuttings required, strata to be sealed off, shooting and chemical treating of wells, water shut-offs, mud-laden fluid, use of mud-laden fluid in setting casing, pulling outside strings of casing, abandoning wells, blow-out prevention, casing requirements for oil and gas production, oil tanks and fire walls, emulsion, B. S., and waste oil, use of vacuum pumps, protection of fresh and artesian waters, burning of gas, protection of mineral deposits, written notices, requests and reports, notice of intention to drill, report on beginning drilling operations, notice of intention to shoot or chemically treat well, report of result of shooting or chemical treatment of well, notice of intention to test casing shut-off, report on result of test of casing shut-off, notice of intention to plug well, report on results of plugging well, miscellaneous notices, miscellaneous reports on wells, well record, supplementary well history, operator's monthly report of operations, request for permission to connect with pipe line, purchaser's monthly reports, notifications of fires and blow-outs at wells and breaks and leaks in pipe lines, pipe-line data required, bonds (covering observance of plugging regulations), special rules and regulations, conflicts between general and special rules and regulations, permissible exceptions to the rules and regulations, enforcement of laws, rules and regulations dealing with conservation of oil and gas, notice to contractors, drillers and others to observe rules, commission to cooperate with proper agents of the United States. See Oil Conservation Commission of New Mexico, Order No. 4.

[75] Proponents of a high density in drilling refer to the statement of W. W. Cutler, Jr.: "Recovery of wells of equal size, producing under similar circumstances in the same pool, is proportional to the average distance that the oil moves to get to the well." See W. W. Cutler, Jr., U. S. Bureau of Mines, *Bulletin 228* (1924), p. 89. This conclusion, however, was based on a study of unrestricted fields. Later Bureau of Mines studies in prorated fields indicated that "spacing of wells wider than that in many fields would have given at least equal recovery during the present 'prorated period' and would have resulted in more efficient use of reservoir energy and lower cost of production." R. A. Cattell and H. C. Fowler, "Fluid-Energy Relations in Production of Petroleum and Natural Gas," in the *Minerals Yearbook, 1934*, p. 715. See also discussion in Ely, 51 *Harvard Law Review* (1938) 1231–1234. Professor L. C. Uren was one of the first geologists to conclude that ultimate recovery of oil would be greater for widely spaced wells than for closely spaced wells. See discussion in J. P. Umpleby, "Production Engineering in 1927," *A. I. M. M. E., Pet. Dev. Tech., 1927*, p. 20.

[76] Ely, 51 *Harvard Law Review* 1232; also see Knowlton, "The Future of Well Spacing," *Oil Weekly*, May 17, 1937, p. 51; and Moore, "The Effect of Curtailment on Ultimate Recovery," A. P. I. release, 1934, cited by Ely. The belief seems to be growing that the area drained by a well is greater if production is at a slow rate; see Hill, "Essential Engineering Factors in the Allocation of Production," A. P. I. release, 1934; also cited by Ely.

[77] Umpleby, *loc. cit.*

[77a] Repressuring cannot establish a solution of gas in oil as complete as that which originally existed in the reservoir.

[78] Cadman, "Conservation of Petroleum," *op. cit.*, p. 2.

Standards of field operation should regulate the abandonment of wells and should relate to the time of abandonment, as well as to the condition in which the hole must be left. This problem is discussed in the following section.

Restriction of Abandonments

Oil and gas wells are abandoned for two reasons, either because of physical circumstances or because of economic conditions in the industry. Usually the abandonments which result from natural operating conditions, such as water encroachment or practical exhaustion of crude petroleum or natural gas, proceed more or less gradually, although it is possible that abandonments might be very high if a large field became widely depleted at about the same time.[79] On the other hand, abandonments resulting from economic conditions under which income falls below cost or under conditions where a much greater net income is promised in new proven territory may be subject to very wide fluctuations.

The problem of well abandonment resulting from depletion is not subject to regulation or to correction, but the premature abandonment of producing wells because of changes in economic conditions may be restricted by regulatory measures. The problem of abandonment of marginal wells is likely to be severe either in periods of very low prices of crude oil or at times when new flush fields are being brought into production. Thus, in 1931, when the price of crude oil in East Texas fell to 10 cents per barrel, and in some instances even as low as 2½ cents per barrel, abandonments throughout the United States became excessive. In 1931, 21,603 wells are reported to have been taken out of production, many of which were only "shut in."[80] The abandonments in 1931 for the first time in the history of the country exceeded the number of wells drilled.[81] The cause was, of course, mainly economic. On the other hand, abandonments were also very high in 1928, when conditions in the oil industry were comparatively favorable. At that time, the main cause was the opening up of several new flush fields.[82] When a flush field is opened, many producers will abandon wells in old fields as fast as they can and transfer their efforts to the new proven territory, where a greater return can be realized, often in a very short period of time.[83]

Regulation of well abandonment was one of the purposes of the Thomas-Disney Bill introduced in Congress in 1934.[84] It was also suggested in a report by the Planning Committee for Mineral Resources to the National Resources Board, in November 1934.[85] Most of the State conservation laws cover the subject of abandonment. In some States one cannot abandon a well without obtaining approval of the State regulatory commission, and then only if a certain procedure is followed (see tabulation of State laws and regulations in chap. 6). Under a system of compulsory unit operation, engineering control of a field would determine well abandonments, since all wells in the field would be operated primarily with the aim of achieving maximum recovery.[86] Without unit operation, a partial solution of the problem of well abandonment could be made if regulatory bodies were able to restrict flush production elsewhere, and particularly if they effectively limited the number of wells which could be drilled in new proven areas of potentially high initial production.

In many areas, a rise in price leads to an increase in wildcatting, which after a while is very likely to result in new flush fields and in high abandonment rates in the older marginal fields.[87] Many have suggested that waste resulting from early abandonment be avoided by the maintenance of comparatively high prices for crude petroleum.[88] Perhaps a comparatively stable price level for crude petroleum might lead to a decrease in abandonments. Even a comparatively high price would not lead to the production of all the recoverable oil. Although severely depressed prices are to be avoided, there are limits beyond which the price of oil cannot be raised by proration and other methods of restricting production. A supplementary method of regulating well abandonment lies in the use of subsidies. Under some circumstances the cost of producing oil may not be more than 15 to 20 percent below the market price, yet the possibilities of a rise in price to cover costs appear remote. If feasible from an administrative view, it would appear to be more satisfactory to grant a subsidy to cover the deficit rather than to try to raise the price of oil throughout the district by the required margin. Such a system of subsidies would, of course, require intimate knowledge of costs on the part of the subsidizing agency, and it might lead to grave administrative difficulties. It does, however, offer a possibility of increasing the ultimate recovery of oil without having to raise prices throughout the industry. The paying of subsidies would need to be linked with a system by which wells were not allowed to stop operations until abandonments had been approved by a regulatory commission. Such subsidization would not, at least for some time, drive down the price of oil, because only a small part of production would come from submarginal wells and because of restrictions on flush production.

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[79] See testimony of George H. Ashley, State Geologist of Pennsylvania, *Petroleum Investigation*, p. 607-608; and also Samuel B. Pettengill, *Hot Oil* (New York, 1936), p. 70.

[80] Watkins, *op. cit.*, pp. 49–50, which quotes testimony of A. L. Beaty at the Hearings on H. Res. 9676, *Oil and Oil Pipe Lines*, p. 71; also Pettengill, *op. cit.*, p. 63.

[81] See statement of Dr. Katharine Carman, petroleum economic analyst, Petroleum Administrative Board, *Petroleum Investigation*, p. 399.

[82] Pettengill, *op. cit.*, p. 70; also George H. Ashley, *loc. cit.*

[83] See testimony of Mr. Otto D. Donnell, president, Ohio Oil Company, *Petroleum Investigation*, pp. 512–513; also Pettengill, *op. cit.*, pp. 67–68.

[84] Pettengill, *op. cit.*, p. 271.

[85] National Resources Board, *A Report on National Planning and Public Works* (short title), December 1, 1934, p. 408; also see Pettengill, *op. cit.*, p. 269.

[86] The landowner's revenue might not stop until the pool was completely exhausted or the pooling agreement might provide that his payments would stop when the well on his land ceased producing. See E. H. Griswold, *op cit.*, p. 40. In any event, the well would be operated not primarily on the basis of its costs and income alone but upon the relationships to maximum efficiency of the operation of the entire pool.

[87] See testimony of Ashley, *Petroleum Investigation*, pp. 607–608.

[88] Pettengill, *op. cit.*, pp. 63–71, where Secretary Ickes among others is quoted as favoring comparatively high prices. Data on abandonments are scanty. The relation between price of crude and the extent of closing in wells needs further study.

Restriction of Production to Current Needs

Regardless of whether unit operation is achievable or not, both oil and gas production need to be restricted by regulatory authorities approximately to current needs. The demand for oil is, of course, somewhat elastic, and consequently the requirements are affected by price. Therefore, a restriction of production to current needs inevitably assumes the maintenance of "desirable" prices or, at least, the restriction of price fluctuations within certain "desirable" limits.

Restriction of production will tend to raise the price, but for many petroleum products demand is fairly inelastic. Thus, the consumption of gasoline, lubricating oils, many light fuel oils, bunker oil, and carbon black probably depends on general business conditions more than upon the price of the materials from which these products are made. Consequently, a rise in the price of oil and gas from the depressed condition of prices, such as existed in 1930 or 1932, may not materially restrict consumption. At times such an increase in price may be justified socially if it operates as it might under favorable conditions of regulation to restrict waste. Under such circumstances it is probably socially desirable that producing companies operate at a profit rather than at a loss. Both economists and judges have held that unless production, particularly from a flush pool, is limited to something like market demand, waste cannot be prevented nor can the correlative rights of the owners of land over the pool be protected.[89] The principle of ratable takings is a firmly established law. Under the restricted flow imposed by proration, producers have gained more technical knowledge concerning the utilization of reservoir energy, and grossly wasteful production practices have been greatly restricted. Thus, proration have helped to promote conservation.[90]

In the main, however, proration continues as a stabilization method, which nevertheless under favorable circumstances can make an important contribution to conservation. Although it has been held that proration offsets the old rule of capture, "the enemy of conservation," [91] it may nevertheless lead to other undesirable operating practices, such as unnecessary drilling and overdevelopment of pools, resulting in well allowables too small to permit an efficient rate of flow. Economists are agreed that of itself proration does not mean conservation and that, as a matter of fact, the results are likely to be to the contrary. Stocking held in 1933 that "where conservation—that is, increased ultimate production—is obtained, it is largely a fortuitous feature of the program." [92] Moreover, Watkins points out that true conservation is "in no wise concerned with a limitation of oil extraction in a given period to any definite amount as representing the estimated 'market demand.' " [93] Yet proration, even as a strict stabilization measure, means avoidance of wasteful storage and protection of reserves of marginal wells. Moreover, proration procedure has improved greatly in recent years. Indeed, restriction of rate of flow (an important element in conservation) to market demand may not differ at times greatly from restriction with reference to maximum recovery.

If the market demand for oil is so small that effective proration leads to the operation of wells at much less than their most efficient rate, proration clearly may damage the reserves.[94] Under such circumstances it probably would be far better for the regulatory body to require the complete closing of part of the fields in the State and the operation of the balance of the fields at an efficient rate.

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[89] Earl Oliver, "State Should Equalize Oil Production," *Oil and Gas Journal*, August 20, 1931, pp. 19 and 100, 101; see also the decision of the Supreme Court in *Champlin Oil and Refining Company* v. *Corporation Commission of Oklahoma*, 52 Sup. Ct. 559; 76 L. Ed. 1062 (1932). In this case the Court sustained the power of the State government to prorate production to market demand. Also see statement of J. Howard Marshal, Petroleum Administrative Board, *Petroleum Investigation*, pp. 2608–2609.

[90] Joseph E. Pogue, "The Economic Structure of the American Petroleum Industry," *Third World Power Conference*, Washington, 1936, sec. II, paper No. 5, pp. 43–44. See also the views of Secretary Ickes to the effect that production restriction and reasonable prices are a prerequisite to conservation. *Petroleum Investigation*, pp. 189–192; also Pettengill, *op. cit.*, p. 65.

[91] Axtell J. Byles, "But One Correction Indicated, Byles Warns North Texas," *Oil and Gas Journal*, March 3, 1938, p. 31.

[92] George W. Stocking, "Stabilization of the Oil Industry: Its Economic and Legal Aspects," *American Economic Review, Supplement*, March 1933, pp. 65–66. Stocking refers to the language of the lower Federal court in *MacMillan* v. *Texas Railroad Commission* to the effect that conservation must be regarded as only an "accidental incident" to such a program of proration. In the District Court of the United States for the Western District of Texas, Austin Division, No. 390 Equity.

[93] Watkins, *op. cit.*, pp. 34–35; see also the opinion of Kemnitzer, *Rebirth of Monopoly*, pp. 217–218.

[94] "A low allowable production may injure a well in the same manner excessive production can cause waste. A well producing large amounts of salt water with the oil may be lost by 'water flooding' if its allowable is so low that pumping must be stopped for several days. If marginal wells cease to operate for a short time, the oil in the structure will 'foam' or 'bubble' and trap recoverable oil by creating an impervious barrier through which the remaining oil surrounding the well cannot pass to the bore hole. Yet, generally excessive produc-

If production restriction is to contribute directly to conservation, it should be accompanied by unit operation or at least by well-spacing provisions. Otherwise the rate of production may be inefficient and, in addition, the use of capital be excessive.

On the other hand, production restriction would be required even under a system of unit operation.[95] Unit operation, in turn, would furnish a mechanism for making proration measures effective. Indeed, in some States so much power might be placed in the hands of a few big companies that continued Federal or State supervision of proration would be advisable. These companies would, unless restrained, undoubtedly work towards a higher and more stable price.[96] Production restriction is essentially a form of monopolistic control with the power of the State supporting it.[97]

The fundamental problem of State quotas is whether they are to be related to the best conservation of reserves or whether they are to reflect merely existing competitive market trends and priority of development. In order that production restriction be equitable and judged insofar as possible on a national basis, it is recommended that a Federal agency estimate market demand and determine the production quotas to be assigned to each State. Such, in essence, was the nature of the petroleum code, and also the provision of the Thomas-Disney bill.[98] Federal proration should prevent a recurrent breakdown of production restriction caused by jealousies between States or by the discovery of important fields in States having no proration laws. Federal proration would be a far more stable regulatory device than the present State-Federal system which allows for interstate settlement of problems primarily by the Interstate Oil Compact Commission.

It is recommended that within each State the distribution of allowables among fields and among individual producing wells continue to be determined by State regulatory bodies, perhaps under the setting of certain minimum Federal standards. Insofar as possible, allowables should be based on acreage content; that is, on estimated oil in place and not on any minimum allowable per well.[99] In a situation such as that in East Texas, where 98 percent of the district allowables are used in prorations per well according to the Marginal Well Act, there is clearly little possibility of basing proration on acreage content or on efficient rate of production.[1] Thus in East Texas the railroad commission can affect allowables for only 2 percent of the production, except by closing down the entire field, as by the Saturday and Sunday shutdowns. Although the Federal courts have declared that the allowable for a good well must be higher than that for a poor one, the Marginal Well Act has forced the railroad commission to deal with over three-fourths of the State's allowable on a basis which ignores any distinction between reservoir conditions or most efficient rates of production.[2] Insofar as proration is consistent with conservation, its goal should be the maintenance of uniform reservoir pressures, and the allowable per well should be readjusted upon the basis of careful measures of comparative pressure declines.[3] Some States try to follow this procedure. If not accompanied by unit operation, proration should be based upon pool allowables and not upon well allowables.

When a new field is discovered, the State should require that wells be closed until production restriction is established. New wells should be held to low rates of flow as long as old wells are producing at less than optimum rates. Drillers of wildcat wells should be required to post bond to guarantee observance of regulations, as is now done in several States. Although wildcat operations, especially by small producers, may lead to excessive competitive drilling,[4] it does not appear

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tion is much more harmful to the oil reservoir than is restricted or small production or even no production at all." Kansas State Planning Board, *Experience of Kansas under Petroleum Production: Control and Conservation Measures* (November 1938) [p. 9].

[95] "As a reenforcement of the proration mechanism, the organization of pool co operatives deserves the active encouragement of all concerned. * * * The attainment of universal unit operation, however, if unsupported by proration, would not provide a solution of the problem of sustaining the life of stripper wells arising from the wide range of costs as between old wells and those kept vigorous by the application of pressure maintenance under cooperative action." Alexander Sachs and Joseph E. Pogue, "Internal Problems of Proration and Oil Conservation," *Transcript of Proceedings of the Interstate Oil Compact Commission*, July 29, 1938, p. 28.

[96] Fraser and Doriot, *op. cit.*, p. 419.

[97] Stocking, *op. cit.*, p. 64n. "So long as you have such arbitrary restriction of the amount of crude oil which is permitted to flow on to the market, price will inevitably be affected. Any monopolist may have a tremendous reserve of capacity and raw materials; but so long as this reserve is not permitted to become supply, it will have no influence on price movements except to the extent that the break-down of monopoly is anticipated." *Ibid.* Also see Watkins, p. 55. These considerations also, of course, apply to the system of restriction under the NRA.

[98] See *Code of Fair Competition for the Petroleum Industry*, p. 8; and Pettengill, *op. cit.*, pp. 272–274.

[99] See Joseph E. Pogue, "An Equilibrium Theory of Proration," *A. I. M. M. E., Pet. Dev. Tech., 1938*, p. 277; W. E. Hubbard, "Economics and Well Spacing in Texas," *A. I. M. M. E., Pet. Dev. Tech., 1937*, p. 170; Oliver, *op. cit.*, *Pet. Dev. Tech., 1937*, pp. 140–142.

[1] Railroad Commission of Texas, *Status of the Allowables of Marginal and Proratable Wells on Oil Proration Schedules*, reports as of October 14, 1938, and January 1, 1939. Marginal wells are pumping wells which produce less than a given minimum set according to the depth of the well—usually about 20 barrels per day. For flowing wells, the Railroad Commission has set a minimum allowable of 20 barrels per day, although legally their allowables might possibly be less.

[2] Ely, 51 *Harvard Law Review*, pp. 1226–1227.

[3] "Allocation of production on the basis of bottom-hole and reservoir pressures seems in general the most equitable, but also it may have the most difficulties to overcome in practical application." C. V. Millikan, "Reservoir and Bottom-Hole Producing Pressures as a Basis for Proration," *A. I. M. M. E., Pet. Dev. Tech., 1933*, pp. 139–141. This method has been used in the Yates field in Texas.

[4] Fraser and Doriot, *op. cit.*, pp. 418–419; and Pettengill, *op. cit.*, p. 87.

advisable to restrict wildcatting unduly, because of the danger of impeding the discovery of new reserves.[5] But new fields must not be allowed to lead to flush production. In this connection, it might be advisable to require that slim-hole drilling be employed wherever oil-bearing strata are not too deep.

Moreover, it is important to note that as a result of the improvement of exploratory techniques new reserves can be at least partially discovered without the necessity of drilling wells with the purpose of obtaining immediate production. As new reserves become more difficult to discover, Government assistance in exploratory activities is likely to be extended.[6] Already the Federal and State governments, particularly through geological bureaus, have given great assistance to drillers in indicating where oil and gas are likely to be found.

Control of Exports and Imports

The problem of regulating foreign trade in crude petroleum and its products should be decided on the basis of conservation of domestic sources of supply and not upon any political basis which may give an advantage to companies operating in certain domestic or foreign fields. Clearly, the reserves of the United States can be made to last longer by restriction on exports and by the encouragement of imports. From this point of view the tariff on oil should be removed. The problem, of course, is a complicated one. It is recommended that the tariff be gradually reduced so that American operating companies can adjust themselves to surrendering a certain part of the Atlantic seaboard market to foreign sources. Of course, political expediency may make it difficult to encourage imports.[7] As a minimum change it is recommended that the tariff regulations be so modified that a larger percentage of the requirements for heavy crude, especially for producing asphalt and for supplying the residual fuel-oil market, be covered from foreign sources of supply.

From the standpoint of maintenance of prices and the encouragement of profits on operations in the domestic market, restriction of imports is clearly desirable, although the importation of foreign crude is not necessarily inconsistent with efforts to adjust domestic production to the domestic demand. In 1926 the Federal Oil Conservation Board recommended that American companies acquire and explore fields in Mexico and South America with the view to protecting the domestic supply of crude oil.[8]

Some foreign countries, however, may object to American companies shipping a rising volume of oil to the United States; and on the other hand, other countries may resent restrictions on exports from this country. The problem may require international consideration with the viewpoint of arriving at a general policy upon conservation and stabilization. Such an international treaty or convention, moreover, would furnish one basis upon which Federal regulation of the industry in the United States could be sustained. Unless unit operation is adopted in the United States, it is likely that imports into this country will be stimulated and exports to foreign markets restricted because of the certain rise in production costs in the United States once new flush pools cease to be discovered every few years; foreign costs as a rule are below domestic costs, mainly because of the existence of more efficient methods of operation, but also owing to lower labor costs.[9] Thus, the present tax of 21 cents a barrel on foreign crude, first levied in June 1932, discouraged imports, but the change from net imports (excess of imports over exports) of 38 million barrels in 1930 to net exports of 40 million barrels in 1937 probably resulted fully as much from the discovery of East Texas and other fields of flush production.

The whole problem of imports and exports needs also to be studied in the light of the fact that American reserves are being more rapidly exhausted than those of foreign countries and that, in addition, the United States is still exporting more petroleum than it imports.

Restriction of Use to Urgent Needs

The conservation of oil and gas resources will be furthered by the allocation of these minerals to the more efficient or superior uses. It is recommended, therefore, that the oil and gas industries be regulated so as to discourage less efficient use. A similar recommendation was made by the Planning Committee for Mineral Policy of the National Resources Board on January 13,

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[5] Cadman, *Conservation of Petroleum*, p. 3; Ely, 51 *Harvard Law Review*, 1231. Ely maintains that the margin of reserves is too small to warrant restriction on exploratory drilling or wildcatting. In addition, the *Code of Fair Competition for the Petroleum Industry* provided that wildcatting was not to be prohibited, "because the future maintenance of the petroleum supply depends on new discoveries and new pools." See p. 10; also included in *Petroleum Investigation*, p. 850.

[6] The State of Mississippi has gone so far as to explore with the aid of the U. S. Geological Survey and drill some of its own properties, *A. I. M. M. E., Pet. Dev. Tech., 1937*, p. 405.

[7] See Pettengill statements, *Hot Oil*, pp. 44–46; see also the testimony of Mr. Wirt Franklin, president of the Independent Petroleum Association, in opposition to the encouragement of imports. *Petroleum Investigation*, pp. 1413–1417; also Pettengill, *op. cit.*, pp. 51–55. As early as 1909, the U. S. Geological Survey condemned exportation of American crudes as a form of "waste"; see U. S. Geological Survey, *Papers on the Conservation of Mineral Resources*, Bulletin 394, 1909, p. 48.

[8] *Report I to the President* (1926), p. 12; also Pettengill, *op. cit.*, pp. 60–61.

[9] U. S. Tariff Commission, *Report to the House of Representatives on the Cost of Producing Crude Petroleum, etc.*, 1932, p. 49; Earl Oliver and J. B. Umpleby, "Principles of Unit Operation," *A. I. M. M. E., Pet. Dev. Tech., 1930*, p. 105, also quoted by Miller and Lindsly, *op. cit.*, p. 1255; and Pettengill, *op. cit.*, p. 54.

1935.[10] Moreover, the elimination of wasteful uses was given as one of the purposes of the Thomas-Disney bill.[11] In his report to the Third World Power Conference, J. C. Dickerman of the Federal Trade Commission recommended that the use of natural gas be restricted to "allowable classes."[12] Even among members of the industry there is some support of the restriction of inferior uses.[13] Most oil and gas producers, however, oppose any restriction of the markets to which oil and gas can be sold.[14]

The problem of efficient use of oil and gas is in part related to the prices of oil and gas in relation to the prices of competing fuels. The reservation of petroleum products to more urgent uses is made difficult by the existence of high or rising prices of coal, coke, and electricity. The anthracite coal industry in particular has been subject to price raising efforts of the dominant concerns, so much so that competition from the oil industry has been practically invited.[15] In addition, the present tendency of Government regulation of the bituminous coal industry is to encourage higher costs—in the direction of shorter hours and higher wage earnings—and rising prices. Witness the intended plans of the National Bituminous Coal Commission to establish a kind of basing-point system with uniform delivered prices within certain marketing territories. The lack of price competition in the coke industry along the Atlantic seaboard has probably also encouraged the use of oil and gas, particularly during certain phases of the business cycle. On the other hand, the effect of recent Government regulation of the electric power industry is in the direction of price reduction. Low prices of coal and electric power are necessary aids to the restriction of inefficient use of oil and gas.

The distribution of oil and gas among various uses is, to some extent, controlled by the net profit in each use, or perhaps more accurately, by the margin of price above estimated direct cost. Thus, the major product of petroleum is one that has a wide margin of this kind and is therefore able to bear a relatively large proportion of the overhead costs. For various uses of the same product, price will probably serve to restrict or prohibit the more economically inferior uses, provided that production is not wasteful or excessive.[16] That is, the uses with the higher utilities will be satisfied first. In the main, the industry prefers that if there is limitation of use it be accomplished by limiting production so that only enough of a given product will be produced to take care of the more efficient uses.[17] In the absence of other provisions such restriction would probably lead to higher prices.

Under conditions of excessive production, inferior and less economic uses of oil and gas make their appearance. There is a rush to sell any product of oil and gas, as there is to sell a product for any use. Fuel oil, which could be manufactured into gasoline, is hurriedly sold for heavy industrial use or as bunker oil and thus displaces coal.[18] Under such circumstances, considerable damage is done to railroads, which must be ready to haul coal in the previous volume if the price of oil rises and buyers shift their fuel needs back to coal.[19]

If production is restricted as was recommended earlier in this section, then the restriction of use would appear desirable. Otherwise, producers will undoubtedly take the higher prices for their major products and continue to sell the byproducts for inferior uses rather than to extend their refining operations at the expense of greater costs and produce more of the superior products.[20] The possibility of requiring that a larger percentage of petroleum and natural gas be devoted to superior uses depends in great measure upon the possibility of manufacturing a larger percentage of the more valuable products. Although refining technique has improved more or less regularly during the history of the oil industry and, as a result, newer refineries are able to obtain as much as a 70-per cent yield of gasoline, a governmental requirement that these high yields be maintained under present cost relationships in the industry would undoubtedly lead to lower average returns on capital investment. If in the light of a conservation program maximum yield of gasoline is deemed important, the Federal Government might consider the possibility of granting capital subsidies in the form of low rates of interest for the construction and operation of the most modern refinery equipment. A rise in the price of gasoline probably would encourage great yields.

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[10] National Resources Board, *loc. cit.* The U. S. Geological Survey in 1909 recognized that there were superior uses of oil and gas; in fact, they associated the principal waste in the petroleum industry with utilization. Bulletin 394, *op. cit.*, pp. 47–49, 59.

[11] Pettengill, *op. cit.*, p. 271.

[12] J. C. Dickerman, "Organization of the Production, Transportation, and Distribution of Naturnl and Manufactured Gas in the United States of America," *Third World Power Conference*, sec. II, paper 6, p. 8.

[13] See statements of C. B. Ames, chairman of the board, the Texas Co., W. S. Farish, chairmnn of the board, Standard Oil Company of New Jersey, and Wirt Franklin, president, Independent Petroleum Association of America, *Petroleum Investigation, 1934*, pp. 362 364, 674, 1395–1396.

[14] Axtell J. Byles, president of the American Petroleum Institute, maintains that "there is no waste of this priceless possession in its current and full use to supply the needs and the comfort of people living today and tomorrow." *Oil and Gas Journal*, March 3, 1938, p. 32. J. Howard Pew, president of Sun Oil Co., maintains that there is no such thing as an inferior use for petroleum. "I deny that there is any use which is inferior to any other use and I do not know that one particular use is superior to another, unless it is perhaps Nujol * * * To say that it is an inferior use to burn fuel oil under a boiler and it is a superior use for people to use gasoline in joy riding, I do not, with all due deference to Judge Ames whose opinions I respect, but I do not get it." *Petroleum Investigation*, p. 383. Note, however, that coal can be burned under a boiler but cannot be used in an automobile engine.

[15] Arthur R. Burns, *The Decline of Competition*, p. 129.

[16] See statement of W. S. Farish, *Petroleum Investigation*, p. 674.

[17] Testimony of Wallace E. Pratt, Humble Oil & Refining Co., *ibid.*, pp. 2176–2177. "* * * then the production would not be sufficient to provide for so-called 'inferior uses' * * * my idea is if a man has an automobile, he has greater need for liquid fuel than a man who has a household heating plant, and that he would pay more for gasoline: that is, the man who uses it for an automobile would pay more than the man with the central heating plant would pay, and that would in itself determine and save Congress the problem that you present." *Ibid.*, p. 2177. Also note remarks of J. Howard Marshall. *Ibid.*, p. 2644.

[18] In times of flush production the result is the improper use of fuel oil, which is dumped upon the market, displacing other fuels. It is sometimes sold for as little as 20 cents a barrel for use as bunker oil. See statement of Wirt T. Franklin, *ibid.*, p. 1396.

[19] Wirt T. Franklin testified that the dumping of imported fuel oil along the Atlantic seaboard in 1931 resulted in a loss of railroad freight revenue of 51 million dollars. *Ibid.*

[20] As Congressman Pettengill stated in discussing the problem with Wallace E. Pratt, of the Humble Oil & Refining Co., "It seems to me, however, it is a little illogical to resist conservation of the use of petroleum products in order to have the largest market possible, and at the same time ask for legislation to curtail production." *Ibid.*, p. 2162.

Under present conditions, to forbid the sale of less valuable byproducts such as fuel oil and gas oil would undoubtedly lead to waste. In order to operate refining companies efficiently throughout periods of varying cyclical and seasonal fluctuations, some freedom of action must be allowed in the percentage of products turned out, and in the markets in which they can be sold. Government regulation on this subject should take the form of stimulating the development of a more desirable practice from the standpoint of conservation and not of any outright prohibition of the sale of any given product, although for some products, particular uses might well be prohibited.

Definition of the urgent need of petroleum products usually leads to the listing of gasoline, lubricating oils, and kerosene. These are the products which yield comparatively high prices. Accordingly, refinery operations should be based primarily on the requirements for these products.[21] More urgent uses for liquid fuel and lubricating oil include the demand for their use by automobiles, trucks, battleships, merchant marine, and other uses for which these products are peculiarly adapted.[22] From the social point of view, it may be very difficult to determine what uses are most desirable. Price, perhaps, is not an infallible index. Thus, the use of natural gas for making carbon black is usually considered more or less wasteful. Yet carbon black has contributed greatly to the life of automobile tires and led to a tremendous saving outside the natural-gas industry.[23] Conservation would require not that the manufacture of carbon black be prohibited but that it be produced as efficiently as possible and from as low-grade fuel as possible.

The restriction of present use undoubtedly will mean the reservation of more crude petroleum and natural gas for future use. Conservation is not primarily a program of sacrificing present consumption in favor of possible future needs. Yet the reservation of part of the reserves for future use is not an altogether undesirable governmental program, because at the present time the nearest substitute for motor fuel would probably cost nearly three times as much to produce.[24]

The regulation of the use of oil and gas may require the taxing of inferior uses, or it may be feasible to require refineries to produce certain minimum percentages of designated superior products. Such a means of regulation would appear, as already stated, to be preferable to outright prohibition.

Continued Governmental Investigation and Research

In order to promote conservation in the oil and gas industry, it is recommended that the Federal Government continue its intermittent investigations into the practices of the industry. The Congressional petroleum investigation of 1934 undoubtedly stimulated an interest in the subject of conservation and brought to the attention of operating companies the necessity of considering the social implications of the industry. Further study of production, transportation, and refining practices might well indicate possible advances in the direction of conservation.

In part, it is the Government's responsibility to see that there is no arbitrary restriction on the use of the best methods of producing and consuming the irreplaceable resources of oil and gas. The present investigation of the Temporary National Economic Committee is the kind of investigation which needs to be carried on from time to time to see that monopolistic influences are not unduly holding up the adoption of patented methods which represent improvements in the direction of more effective utilization of oil and gas. It is especially important to see that maximum gasoline mileage is being obtained, that the efficient Diesel motor is being introduced as rapidly as possible, and that the most efficient refinery procedure is available to all.

Technical Government research into the production problems of the industry should be continued. In the main, Federal agencies are better equipped for this purpose, but there is no reason why important contributions cannot be made by State laboratories and research bureaus.[25] The achievements of the Bureau of Mines and other Federal bureaus have made noteworthy contributions toward improved methods of production, refining, transportation, methods of consumption, and the use of byproducts.[26] In several instances the Bureau of Mines has developed and made available to operating companies improved methods of manufacture, such as the vapor-phase cracking process, which was developed by the Bureau of Mines and offered to the industry in 1916.[27]

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[21] Wirt T. Franklin, *Petroleum Investigation*, p. 1396. That petroleum is absolutely necessary for lubricating purposes was emphasized by the U. S. Geological Survey as early as 1909; Bulletin 394, *op. cit.*, p. 48.

[22] Wallace E. Pratt, *Petroleum Investigation*, p. 2177.

[23] John D. Gill and E. T. Knight, "What are the Uneconomic Uses of Petroleum?" *A. I. M. M. E., Pet. Dev. Tech., 1938*, pp. 286–288. It is estimated that a tire made with carbon black lasts two and one-half to three times as long as tires made with the next most suitable material. It is stated that "over the last 15 years, the saving to the public in the form of longer-life tires has been upward of 40 times as much as the value of natural gas employed for the production of all carbon black manufactured in this country for whatever purpose, even when valued at the well at the average price realized for natural gas from the same source * * *."

[24] It has been estimated that motor fuel from coal can be produced for 12 cents. *Petroleum Investigation*, p. 1400.

Government Ownership

From time to time proposals have been made that the United States add to the present naval and other governmental reserves by purchasing outright additional proved oil and gas territory. In this manner the Government has acquired the important helium reserve in the Panhandle of Texas.[28]

The complete nationalization of all oil rights in line with the procedure followed by Germany and other countries has been discussed from time to time in the Federal Congress. In the first session of the 75th Congress (1938) a resolution was introduced by Representative John M. Coffee, of the State of Washington, providing for the nationalization of the oil industry.[29] The acquisition of all oil and gas rights in this country, however, would probably be an impossible task, since it could be carried out only by the purchase of these reserves under the right of eminent domain.[30] It would probably be much more feasible for the Federal Government to pass laws taking over the title to undiscovered oil rights as was done in Great Britain. As an alternative, the Government might survey the remaining unexplored territory and purchase the more favorable locations. Yet a more effective expression of the Federal interest in oil and gas production could probably be carried out by regulation looking toward the adoption of conservation practices.

Prerequisite Federal and State Legislative Measures

If adequate grounds for direct Federal regulation of the oil and gas industry are constitutionally available, as many have suggested,[31] the regulatory system may be comparatively straightforward. If necessary, indirect Federal regulation may be achieved by the use of State subsidies or the rebate of Federal taxes. The question of a legal basis for Federal and State regulation of the oil and gas industry is discussed later.

Federal Oil and Gas Conservation Body

Specifically, it is proposed that a Federal oil conservation board or commission be created to administer the Federal interest in the oil and gas industry and to make necessary rules and regulations covering the production, treating, and refining of oil and gas. The board should take over the powers now held by the Interstate Commerce Commission with respect to the transportation of oil and gasoline and the powers of the Federal Power Commission over pipe line movements of natural gas. It should have the power to regulate the extension of pipe lines or railroads to new oil fields, the power to allocate production quotas among producing States (discussed below), and the power to require that oil and gas which are to be transported in interstate commerce be extracted by such methods as are adequate to avoid waste and protect the interest of all producers drawing from a common reservoir.[32]

In view of the production conditions in the oil and gas industry, it appears that the maximum of comprehensive social benefit from these resources requires a far-reaching authority from control of production to control of competitive energy.[33] Consequently it is proposed that such a regulatory commission be related to similar boards or commissions regulating the production, distribution, and use of coal, water power, and electric power. An energy resources division might well be established in some Federal department, perhaps in a new Department of Conservation or of Minerals.

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[25] Technical research can be more efficiently executed by the Federal Government rather than by some technical division of the Interstate Oil Compact Commission, such as was recommended by Alexander Sachs in an address before the annual meeting of the A. I. M. M. E. *Oil and Gas Journal*, February 24, 1938, p. 57.

[26] See, for example, H. C. Fowler, *Petroleum and Natural-Gas Studies of the Bureau of Mines*, Information Circular 6737 (July 1933); Boyd Guthrie, *The Bureau of Mines and the Oil Refining Industry*, a speech delivered before the regional technical meeting of the Western Petroleum Refiners Association, Tulsa, Okla., October 5, 1937, and released by the Bureau of Mines, and also an accompanying list of publications of the Bureau of Mines dealing with chemistry and refining of petroleum; and *A Selected List of Bureau of Mines Publications and Motion Picture Films Dealing with Petroleum, Natural Gas, Helium, Oil Shale, and Allied Subjects*, issued by the Bureau of Mines through the petroleum experiment station, Bartlesville, Okla., in cooperation with the State of Oklahoma (June 1, 1937).

[27] W. F. Rittman, C. B. Dutton, and E. W. Dean, *Manufacture of Gasoline and Benzine-Toluene from Petroleum and Other Hydrocarbons*, U. S. Bureau of Mines Bulletin 114 (1916).

[28] The Cliffside gas field, controlled by the Federal Government, is estimated to contain a reserve of 100 billion cubic feet of natural gas, with a probable helium content of 1.8 billion cubic feet. *Minerals Yearbook, 1938*, p. 975.

[29] H. Res. 7024.

[30] Statement of C. B. Ames, *Petroleum Investigation*, p. 358.

[31] See the proposals of Henry L. Doherty, included in Federal Oil Conservation Board, *Public Hearings*, May 27, 1926, as well as the favorable comment by Donald H. Ford, "Controlling Oil Production," 30 *Michigan Law Review* 1170 (1932); referred to in Northcutt Ely, *Oil Conservation through Interstate Agreement*, Federal Oil Conservation Board (1933), p. 15.

[33] Similar provisions were proposed by James G. Stanley, former counsel general of the Continental Oil Co. in 1931, "Call for Federal Regulation Discussed," *Oil and Gas Journal*, September 17, 1931, pp. 24, 98, 99. It was also proposed that such a board might refuse an application to extend pipe lines or rail lines to new fields if the quantity of oil on the market was sufficient to meet domestic needs.

[33] See Judson C. Dickerman, "Organization of the Production, Transportation, and Distribution of Natural and Manufactured Gas in the United States of America," *Third World Power Conference*, Sec. II, paper No. 6, Washington, 1936, p. 8. Dickerman also suggests a determination of the allowable classes of use for natural gas.

Strengthening of the Connally Act

It is proposed also that the Connally Act be amended so that the act will provide for the prohibition in interstate commerce of oil and gas produced in violation of Federal as well as State laws. Under the present act the States regulate for the Federal Government, in effect, deciding what oil can be transported between the States. It is further recommended that the act apply as well to natural gas and to gasoline. Likewise, it should be provided that the Interstate Oil Compact include the Federal Government as a member,[34] and that the compact, to be an effective part of the State regulatory system, include representatives of all producing States. Moreover, some Federal agency should be given the power of setting compulsory production quotas for States by months, after consultation with the members of the Compact or some similar advisory commission or commissions representing oil and gas producing States. These allowables would have to be enforced by means of the control over movement of crude, perhaps by an extension of the present system of tenders in use in East Texas.

If production is adequately regulated, it will probably be unnecessary to set quotas for petroleum refineries, although such a provision might be considered as a protective device in providing for the observance of the regulatory features relating to production.[35]

Modification of State and Federal Antitrust Laws

Antitrust laws should be modified wherever necessary to allow unit operation and to exempt from the interdictions of the antitrust laws agreements for the cooperative exploitation of a single pool provided the public interest is safeguarded.[36] Such a provision is all the more necessary if unit operation has to proceed on a voluntary basis. Indeed, some State laws lack such a waiver.

Pipe-Line Divorcement

Further study should be given to the proposal that integrated or semi-integrated oil companies be required to divorce themselves of their pipe-line holdings. It may be that the independence of the pipe-line systems would facilitate a system of regulation, under which the Federal interest is paramount, and in particular, that under such a system the opening of unnecessary fields and unnecessary wells could be restricted by the prohibition of pipe-line extensions, and, in addition, that the restriction of production to demand could be made more effective. Divorcement has been proposed at various times by independent producers, who have complained that pipe lines do not observe the State regulations relating to receipt of crude and pipe-line charges. Divorcement was recommended by the President of the United States on April 3, 1933.[37]

On the other hand, representatives of integrated oil companies have maintained that the divorcement of pipe lines would harm the efficiency of large producers and that a pipe-line system is an integral part of a large concern, just as essential to its effective operation as is a refinery. It has been maintained that pipe-line facilities are more than adequate, that in no territory is there a monopoly to any one company, and that separate ownership of pipe lines would lead to discrimination against many small producers of crude. It is also held that the pipe-line systems would be an unprofitable investment, the implication being that integrated companies now furnish transportation service at cost to themselves and their customers. Profits, however, apparently have been liberal.[37a]

Perhaps granting to the Interstate Commerce Commission the power to initial rate changes, as under the present Lea omnibus bill, would give the Federal Government sufficient control over pipe-line movements of oil and gasoline.

Public Utility Status

It is recommended that the advisability and possibility of declaring the petroleum and natural gas industries public utilities be investigated. Although oil and gas production is usually regulated by the same commissions which regulate public utilities, it is in the comparative lack of control over the amount of investment that States distinguish the oil industry from the utilities. With a public-utility status placed on the industry, commissions, both State and Federal, would have more effective grounds for controlling drilling, proration, and production, and the transportation of oil and gas in State and interstate commerce. Such a status, however, may be difficult to establish. A Tennessee statute imposing a public-utility status on the selling of gasoline was held invalid by the Federal courts.[38]

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[34] The entrance of the Federal Government in the compact as a cooperating agency has been proposed by Governor Huxman, of Kansas. See a report to the National Resources Committee, on *Experience of Kansas under Petroleum Production*, November 1938, pp. 11, 14–20. The Kansas State Planning Board has recommended giving the compact more power to control production.

[35] See the proposals of Chairman Ernest O. Thompson of the Interstate Oil Compact and also of the Texas Railroad Commission, *Journal of Commerce*, October 21, 1938, p. 1.

[36] See Stanley, *op. cit.*, p. 99.

[37] For the President's proposal, see *Petroleum Investigation, 1934*, pp. 1423, 1617. For statements of the Independent Petroleum Association opposed to monopoly and of other representatives of independents, see *ibid., pp.* 2093, 2110, 2363–64, 2372.

[37a] For the viewpoints of J. Edgar Pew, president of the Sun Oil Company, see *ibid.*, pp. 2049–53, and of Frank Phillips, see *ibid.*, p. 1617. On profits, see *ibid.*, pp. 1616–17, 2390. One estimate of profits was as high as 25 percent.

[38] *Williams* v. *Standard Oil Company of Louisiana*, 278 U. S. 235 (1929); quoted in Ely, 51 *Harvard Law Review* 1224–1225. "That

In any event, the history of public utility regulation, especially the determination of "fair rate of return" and "fair valuation" does not give much promise that this method of supervising the oil and gas industry would be immediately satisfactory.

Change in Concept of Ownership

In many States the courts have already modified the rule of capture so that a landowner can recover only a certain amount of oil within a given period. The setting of "ratable takings" and of well-spacing provisions has been established as part of the regulatory systems of most oil-producing States and upheld by the State courts, with the important exception that many States provide that a certain minimum allowable must be given to all wells in the State. In Texas these marginal well provisions absorb such a large percentage of the total proration for the State that the Texas Railroad Commission has no discretion over the allotment of almost three-fourths of the State's allowable.[39] Although the right of capture has been modified somewhat, it needs to be completely displaced by a thoroughgoing law of ownership in place, which would allot to each producer that proportion of the oil and gas in the common reservoir which underlies the land he owns or controls.[40] A "ratable taking" based primarily on oil in place was proposed by the allocation committee of the American Petroleum Institute.[41]

The concept of ownership of oil and gas resources cannot be changed unless acreage content of these resources can be measured with reasonable accuracy. Judges probably would follow the engineers in substituting acreage content if they had confidence in the ability of the engineers to check each other within reasonable bounds.[42] Engineers of the Bureau of Mines maintain that the technical problem has been solved provided that the necessary data for such measurements are obtained.[43] Under present methods of development and operation these data are not collected, but under unit operation they could be without entailing much production. Others have maintained that engineers cannot actually determine oil in place under a particular tract of land.[44] Moreover, the Texas Supreme Court decided on June 12, 1935, in *Brown* v. *Humble Oil and Refining Company*[45] that although the rule of capture was still in effect "it is now recognized that, when an oil field has been fairly tested and developed, experts can determine approximately the amount of oil and gas in place in a common pool, and can also equitably determine the amount of oil and gas recoverable by the owner of each tract of land under certain operating conditions." In a recent case upholding an Oklahoma well-spacing act, the Supreme Court of that State held that, within spacing units, the production of petroleum was equitably divided on an acreage basis.[46] This case assumes that in small plots the ownership of oil in place is proportional to the surface acreage.

A more difficult problem relates to the ownership of reservoir energy: whether it should be allocated among common owners of the oil pool or whether it should be valued on some fair basis and credited to owners of land above the water-drive and gas caps as well as above the oil pool.[47] Another problem relates to the introduction of new lease forms which will allow the assignment of rights to the operator of a unit pool plan. Standard conservation clauses could be substituted for the clauses in most leases now requiring immediate development and production.[48] The use of some kind of community lease or a similar modified lease form, which will free the company from the obligation of operating the well according to fixed conditions is a necessary preliminary to a plan of unit development, either compulsory or voluntary.[49]

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statute represents one of the very few attempts to bring any phase of the oil business (save transportation) into the public utility fold."

[39] Railroad Commission of Texas, *Status of the Allowables of Marginal and Proratable Wells on Oil Proration Schedules* effective January 1, 1939. In the East Texas Field, 98 percent of the production comes in under the marginal well statute.

[40] Such suggestions have been made by the following: Earl Oliver, "Changes Needed in Oil Ownership Law," *Oil and Gas Journal*, July 23, 1931, p. 15; Henry M. Bates, Dean of the Michigan Law School, "Some Constitutional Aspects of the Oil Problem," *A. I. M. M. E., Pet. Dev. Tech., 1935*, p. 199; H. D. Wilde, Humble Oil and Refining Company, *A. I. M. M. E., Pet. Dev. Tech., 1931*, p. 42; Eugene A. Stephenson, "Acreage and Potential Factors in Allocation," *Pet. Dev. Tech., 1937*, pp. 172–73.

[41] Stephenson, *loc. cit.*

[42] *Oil and Gas Journal*, October 15, 1931, p. 32; Pettengill, *op. cit.*, pp. 89 and 96.

[43] H. C. Miller and Ben E. Lindsly, then petroleum engineers of the U. S. Bureau of Mines, testified in *Petroleum Investigation* that "there is no technical reason why the quantity of oil and gas in the reservoir cannot be estimated with reasonable accuracy and allocated to the owners of the gas and oil rights in fair proportion to the amount originally under their surface holdings." *Petroleum Investigation*, p. 1271; also see Earl Oliver, "Can the Rule of Capture be Rationalized?" *A. I. M. M. E., Pet. Dev. Tech., 1937*, pp. 140–41–42; and also F. O. Martin, Geologist, Union Oil Company of California, *A. I. M. M. E., Pet. Dev. Tech., 1928*, p. 781. Martin believes it should be based on acreage.

[44] See, for example, J. R. Parten, "Unit Operation Would Not Work to the Good of the Majority," *Oil Weekly*, December 18, 1931, pp. 20, 69–71.

[45] 126 Tex. 296, 83 S. W. (2d) 935 (1935); Cf. Pettengill, *op cit.*, p. 89.

[46] 77 Pacific (2d) 83. This decision was based on the Oklahoma State Law, S. L. 1935, 52 Okla. St. Ann. par. 87, subd. (C).

[47] On this problem see "Reservoir Energy: Its Source, Ownership, and Utilization in the Production of Petroleum," *A. I. M. M. E., Pet. Dev. Tech., 1933*, pp. 23–28.

[48] See Ely, 51 *Harvard Law Review* 1239; also see Umpleby, *A. I. M. M. E., Pet. Dev. Tech., 1930*, p. 428.

[49] See also Fay L. Wright, "Some Economic Aspects of the Community Oil Lease," *A. I. M. M. E., Pet. Dev. Tech., 1925*, pp. 769–771; and statement of E. A. Stephenson, *A. I. M. M. E., Pet. Dev. Tech., 1933*, p. 41.

Question of Legal Basis for Regulation

Legal Basis for Federal Regulation

Perhaps the strongest basis for Federal regulation of production and distribution of oil and gas lies in the Federal Government's power to regulate interstate commerce. The commerce clause of the Constitution has been broadly interpreted in the last 2 years. The cases relating to the power of the National Labor Relations Board to regulate industrial relations of companies engaged in interstate commerce indicated in 1937 that the commerce clause applies to industrial concerns which obtain a majority of their raw materials from other States and which sell most of their products to customers in other States.[50] Moreover, the Federal courts have held that although activities may be intrastate in character, when separately considered, Congress cannot be denied the power to regulate them if they have such a close relation to interstate commerce that their control is appropriate to protect that commerce from obstruction.[51] If industries are organized on a national scale so that their activities are predominantly interstate in character, the industry can be regulated under the commerce clause.[52]

More recently the power of the Federal Government over interstate commerce has been extended in the case of the *National Labor Relations Board* v. *The Consolidated Edison Company of New York*, where it was held (Chief Justice Hughes writing the opinion) that the Federal Government has jurisdiction over a company whose operations are entirely intrastate in character, provided that the concern furnishes services essential to the maintenance of interstate commerce.[53] The opinion pointed out that serious interruptions might occur in interstate and foreign commerce if industrial strife stopped the operation of the services of the Consolidated Edison Co. Moreover, it was held that the exertion of Federal power does not have to await the disruption of that service.[54]

This decision would seem to furnish a basis for Federal regulation of production of oil and gas and of conservation measures looking to the protection of the public against the waste of an irreplaceable resource. The production and transportation of oil and gas make up a stream of interstate commerce so continuous and so widespread that a national economic policy under Federal control is clearly in the public interest.[55]

Moreover, the various antitrust cases seemed to indicate the considerable extent of the Federal power under the commerce clause to correct recurring and continuous abuses in competitive practices which lead to interstate demoralization of one sort or another in the market. In addition, *Chicago Board of Trade* v. *Olsen* seemed to indicate that anything which produces violent fluctuations in a national market for a socially necessary product is subject to Congressional control.[56] Conservation of oil and gas and interstate commerce in these commodities would appear to be so closely related that the industry is a matter of Federal regulation. Ineffective conservation of oil and gas resources will hasten the rise in prices which many of the agencies of commerce will have to pay for their fuel.[57] The continued waste of oil and gas and the early threatened exhaustion of limited resources might result in a far more severe interruption to interstate commerce than would a strike in an electric power plant in New York City. The Federal Government's power over this basic national industry would appear to be essential. Insofar as it is necessary to make Congressional control of interstate commerce effective, Congress possesses the power to make proper and reasonable regulations of interstate activities, including the regulation of property.[58]

Almost equally important as a basis for Federal regulation is the power of the Federal Government to provide for the national defense. The World War demonstrated the military significance of petroleum, and, under present methods of warfare, gasoline and fuel oil have become indispensable.[59] Men in the industry,[60] attorneys,[61] and Government agents[62] have from time to time indicated that petroleum is crucial to our national safety. Most attorneys agree that if war were imminent Congress could be empowered to control oil production.[63] Whether the national-defense clause furnishes an adequate basis for peace-time regulation is another question. As long as the prerequisite legislation was a "reasonable" exercise of the war power, it would be upheld as constitutional,[64] but attorneys do not agree on what action would be "reasonable." Many argue that the Government should control the reserves even in times of peace so that oil will be available in the future at a reasonable price.[65] There are others who argue that the Government could acquire sufficient reserves through condemnation.[66] Still others believe that the Government should purchase oil fields and close them in until such times as they are needed.[67] In any event conservation of oil and maintenance of adequate reserves are sufficiently basic to national defense to justify attempts at regulation, regardless of whether war appears immediately imminent.

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[50] *National Labor Relations Board* v. *Jones and Laughlin Steel Corporation; National Labor Relations Board* v. *Freuhauf Trailer Company;* and *National Labor Relatians Board* v. *Friedman-Harry Marks Clothing Company, Inc.;* 301 U. S. 1, 37, 53, 54, 72–74 (April 12 1937).

[51] *National Labor Relations Board* v. *Jones and Laughlin Steel Corporation,* 301 U. S. 1 (1937).

[52] *National Labor Relations Board* v. *Jones and Laughlin Steel Corporation,* 301 U. S. 41.

[53] 83 Law Ed. 131; also see *New York Times* press dispatches, December 6, 1938, pp. 1, 20. In pointing out that The Consolidated Edison supplies electricity to major railroads operating out of New York, to the Port of New York Authority, Holland Tunnel, steamship piers, telegraph and radio corporations, and to Government activities, including the post office, Chief Justice Hughes said, "It cannot be doubted that these activities, while conducted within the State, are matters of Federal concern. In their totality they rise to such a degree of importance that the fact that they involve but a small part of the entire service rendered by the utilities in their extensive business is immaterial in the consideration of the existence of the Federal protective power."

[54] *Ibid.,* p. 20.

[55] James G. Stanley, *op. cit.,* p. 24.

[56] See testimony of J. Howard Marshall, member of the Petroleum Administrative Board, former special assistant to the Attorney General, and member of the Federal Tender Board in the East Texas field, *Petroleum Investigation, 1934,* pp. 2614, 2616. For further discussion of the problem of Federal regulation see *ibid.,* pp. 2640–2646.

[57] *Ibid.,* p. 2618.

[58] Shreveport Rate Cases, 234 U. S. 342; *McDermott* v. *Wisconsin,* 228 U. S. 115. See also Henry M. Bates, *op. cit.,* pp. 201–205.

[59] It is estimated that during 1938 the Navy Department alone consumed 8.2 million gallons of fuel oil, 235,000 gallons of Diesel oil, 10.5 millions of aviation gasoline, and 5.2 million gallons of gasoline. Of course, these requirements would be many times increased in case of war. In fact, the need in time of war is so great that the Navy will continue to supply its requirements from commercial production and retain its own petroleum reserves against possible depletion of commercial fields.

An additional base for Federal action would seem to lie in the taxing power of the Government. Wasteful practices might be restricted, and efficient unit operation provided for, by Federal measures based at least in part on the power of the Government to tax for the general welfare.

Legal Basis for State Regulation

State regulation of the oil and gas industry is based upon the police power and its use to provide for the general welfare. It has been suggested that this power is already sufficient for the initiation of a system of unit operation,[68] although a further change in the law of ownership of mineral rights would probably be required. To date, State statutes controlling flush production and regulating drilling have been based on the State's power both to protect a natural resource against waste and to protect joint owners of a common pool. Of the leading oil-producing States, California leans to the correlative rights basis, Texas to the waste basis, and Oklahoma's statutes rest on both.[69] More recently, the Federal court in Texas has approved the restriction of natural gas production on the basis of correlative rights.[70] In this decision the judges pointed out that the sour gas proration law was "almost a necessary exercise of the police power to protect owners of wells, whose unrestricted right of capture the statute has lawfully invaded in order to protect the gas reserves from dissipation in inferior uses, from having their gas drained away by the disproportionate takings of other owners from the reservoir." The Texas Railroad Commission's contention, upheld by the court, was that the operators had produced all the gas originally underlying their land and that no injury was shown by the restriction.[71] The State's right to regulate production has also been based on the general power to abate nuisances and more recently in some States upon the power to restrict production for purposes of economic stabilization without reference to conservation.[72] The recent Oklahoma decision, *Patter-*

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[60] Wirt Franklin, president of the Franklin Petroleum Company, said, "* * * our only safety as a Nation lies in providing that the oil industry shall at all times be kept up to the highest pitch of efficiency," *Petroleum Investigation, 1934*, p. 1400. In this connection, see the proposals of Henry L. Doherty, Federal Oil Conservation Board, *Public Hearings*, May 27, 1926, pp. 24–26, 64.

[61] Statement of James A. Veasey, then general counsel of the Carter Oil Co., *Petroleum Investigation, 1934*, p. 1722; also James G. Stanley, "Call for Federal Regulation Discussed," *Oil and Gas Journal*, Sept. 17, 1931, pp. 24, 98, 99; also addresses delivered by Dean Henry M. Bates, of Michigan Law School, and Dean Roscoe Pound, of Harvard Law School, before the petroleum division of the A. I. M. M. E. in New York City on February 22, 1934, quoted in *Petroleum Investigation, 1934*, pp. 1564 74. Dean Pound declared: "* * * * if there is one thing the books do insist upon, it is that petroleum is the very vitals of preparation. I say if the Pacific roads could be built by the Federal Government under the war power, I don't see why petroleum couldn't be conserved on the same basis."

[62] Secretary Harold L. Ickes has from time to time stated his belief that the Government should control oil production to safeguard petroleum reserves for national defense, *Petroleum Investigation, 1934*, p. 168; also an address entitled "Oil and the World We Live In," delivered in Houston, Texas, October 15, 1937; and a statement by Secretary Ickes before a Subcommittee of the Committee on Finance, United States Senate, *Hearings on S. 790, February 1937*, Washington, 1937, p. 4. Recently Secretary Ickes said, "I think that the United States has been remiss for a long time in not having passed a regulatory act which would stop waste and conserve our oil for future generations. This is particularly important now in view of the fact of its relationship to what we are doing for national defense," *New York Times*, November 4, 1938, p. 48, and Henry D. Ralph, "Ickes Still Prefers Federal Oil Control," *Oil and Gas Journal*, November 10, 1938, p. 28, statement by Norman L. Meyers, then chairman of the Federal Tender Board, *Petroleum Investigation, 1934*, p. 1988.

[63] For example, statement by Veasey, *ibid.*, p. 1720.

[64] *Ibid.*, p. 1721.

[65] Nathan R. Margold, then chairman of the Petroleum Administrative Board, and also the solicitor of the Interior Department, held that "* * * looking ahead beyond that and into the future, it is well for the nation to have even a privately owned supply for its use at the time when the need arises for the Government to acquire it, and it is well for the Government to be able to get it at a fairly reasonable price. The cost is something which Congress could have in mind, and Congress can compel conservation of presently available cheap sources of supply of oil and the continuance of that cheap supply for a much longer period of time." *Petroleum Investigation, 1934*, p. 437. This same viewpoint is held by Wirt Franklin, *ibid.*, p. 1426, and Norman L. Meyers, *ibid.*, p. 1988. Margold further states that "* * * the courts have held that the Federal Government has the power to establish naval reserves under the war power. If it has power to have and to conserve the supply, I do not think that it can be said under any conceivable circumstance that Congress would be acting capriciously if it declared and found, and legislated accordingly, that it was in the interest of the national defense to preserve for a long time our chief source of petroleum through compulsory scientific development of oil field and curtailment of production to market demand." *Ibid.*, p. 480.

[66] W. S. Farish, chairman of the board, Standard Oil Company of New Jersey, *Petroleum Investigation, 1934*, p. 749.

[67] Ernest O. Thompson, member of the Texas Railroad Commission, *Petroleum Investigation, 1934*, p. 1806.

[68] Bates, *op. cit.*, p. 199.

[69] For citations see Ely, 51 *Harvard Law Review* 1223.

[70] "Order on Sour Gas Quota Upheld in Federal Court," *Oil and Gas Journal*, July 28, 1938, p. 79.

[71] *Ibid.*

[72] See discussion by Ely, 51 *Harvard Law Review* 1222–1225; also "Acreage Content Standard or Ownership," *Oil and Gas Journal*, October 15, 1931, p. 32; also LeRoy H. Hines, *Some Aspects of Unit Operation of Oil and Gas Pools and Fields*, U. S. Geological Survey, 1934, pp. 11–13.

son v. the Stanolind Oil and Gas Company,[73] would seem to indicate that tract unit operation may be provided for under well spacing statutes, which allow only one well to a certain acreage regardless of ownership. Complete field unit operation would raise additional problems, particularly relating to the rights of the owners of the gas cap: but this case seems to offer an avenue of extending the State's power in the direction of enforced unit operation. In part this case hinged upon the greater return which the owners of property might obtain under more coordinated production. It has been suggested that unit operation could be achieved by a State law, based upon the correlative rights theory, which made the joint owners of the pool tenants in common on the basis of proportionate determination of the contents of the pool.[74] A method of setting up unit operation was suggested by J. A. Veasey, general counsel for the Carter Oil Co.,[75] in discussing the *Cedar Rust* case, in which the Supreme Court of the United States held that under its police power the State of Virginia could order the destruction of infected cedar trees within a designated radius of apple orchards without compensation to the owners of the cedar trees. Veasey suggested that a police measure could be adopted which would defer the use or limit the production of free gas at the top of a reservoir or of gas in association with petroleum in the case of properties having an advantage with respect to reservoir energy. This would seem to open the way for unit operation of a pool and for deferred capture of the free gas. The gas owner would have to wait until all the oil was produced from his property. Or some equitable method of evaluating the gas might provide more effectively for a sharing of the gross pool receipts among the joint owners of both oil and gas. If the State has the power to regulate reservoir energy, this could be made an effective wedge for the adoption of unit operation.[76] Suggested State bills providing for voluntary unit operation were issued by the Federal Oil Conservation Board.[77]

The economic advantages of unit operation and scientific management of oil and gas pools are so overwhelming and so generally approved by technicians that some legal device of providing for their adoption and enforcement will surely be forthcoming as the threat of exhaustion becomes more severe.[78]

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[73] 77 Pacific (2d) 83.

[74] Charles G. Haglund, 22 *Kentucky Law Journal*, 564–565 (May 1934); see also Earl Oliver, "Can the Rule of Capture Be Rationalized?" *A. I. M. M. E., Pet. Dev. Tech., 1937*, p. 151.

[75] *A. I. M. M. E., Pet. Dev. Tech., 1933*, pp. 26, 27.

[76] Robert E. Hardwicke, "Legal Aspects of Gas Conservation," *Oil and Gas Journal*, June 25, 1931, p. 17.

[77] *Report III to the President of the United States, 1929*, pp. 40–49.

[78] Cf. the statement by H. S. Gibson, "Scientific Unit Control," *Science of Petroleum*, I, 539.

PART ONE—SECTION III

POTENTIAL WATER POWER IN THE UNITED STATES

By J. P. Watson*

CHAPTER 1.—INTRODUCTORY EXPLANATION OF DATA

Total stream energy is dependent on how much water flows and how far it falls in its course. The amount of power that may be obtained from a stream, however, depends both on engineering and on economic and social policy.

Appropriation of water power is mainly in the form of generation of electricity. From a sheerly physical point of view, the amount of energy obtainable is dependent on the proportion of the stream flow that can be harnessed and the efficiency of hydroelectric generating plants. The maximum proportion of stream energy that, in physical terms, might be obtained is dependent on the degree to which geologic, topographic, and hydraulic limitations would permit the engineers, with full use of their techniques, to harness the stream in accordance with the requirements for efficient operation of generators. Obviously, the merely physical interpretation of potential water-power is dependent on data regarding flow, profile of stream bed, geology, topography, and engineering technique—all of which, being incomplete, are subject to revision.

But the uncertainties regarding the amount of water power available are vastly extended by questions of economic feasibility and public policy.

If considered for power alone in terms of ordinary business criteria, development of a given power site is feasible only if there is an existing or reasonably prospective market for electrical energy, within economic reach of electrical transmission from that site, which cannot be supplied more cheaply by fuel-generated power. Obviously, feasibility in those terms may arise or disappear with changes in composition of the market or changes in the relation between delivered cost of hydroelectric energy and delivered cost of equivalent energy generated from fuel.

Even a clear judgment on business feasibility, however, would give no final answer: for life and comfort depend on numerous nonpower uses of water resources. Governments must deal with water problems for the adequate solution of which private business has neither organization, authority, technique, nor motivation. Such problems include public water supply, floods, irrigation, erosion, pollution, malaria, and navigation. Most of these public problems are present on any stream large enough to offer promise of significant water power. Under some circumstances use or control for purposes other than production of power may limit the use of water for power, although the possible conflict of purpose appears to have been overmagnified. On the other hand, the construction of dams for the attainment of control over stream flow may greatly increase the potential firm (continuous) power at sites already deemed feasible in terms of power alone, and it may make production of power quite possible and economic at sites not feasible in terms of power alone.[1]

In view of the complexity of technical, economic, and social considerations, the estimates of potential water power considered here should be taken only as useful approximations made in the light of present knowledge of essential physical facts, judgments of existing and future markets, and judgments of the trend of public policy regarding regulation of streams.

A general national view will be given first. Greater attention, however, will be given to the regional estimates, in relation to regional use of energy and regional availability of other sources of energy. To aid in interpreting the economic position of water power, attention will then be given to (a) system interconnection, and (b) the competitive relationship of water power and fuels. The final chapter will deal with water-power policy. Reference data, except as otherwise noted, are provided in tables 1 to 6.

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[1] This question of power and nonpower uses is examined later, in ch. 6, under the heading "Power in the Multiple-Purpose Project."

CHAPTER 2.—ESTIMATED NATIONAL WATER POWER

Potential water power was estimated in 1936 at 42,753,000 horsepower available 90 percent of the time or 57,184,000 horsepower available 50 percent of the time. These estimates, prepared by the Geological Survey, were computed with allowance for the control of stream flow made possible by storage reservoirs then existing and with corresponding allowance for probable future storage, insofar as storage possibility had been evaluated; an overall efficiency of 70 percent at the sites was assumed.[2] The extent to which this power has been developed and the output of energy considered feasible from water power will be considered presently.

Influence of Storage

In the allowance for future storage, consideration has been given to "known reservoir sites," except many small sites—possibly of value to local communities but not large in terms of total potential power. It is noted, also, that, in general, the best estimates are those of the states with larger power resources, in which the surveys are more complete, and that, as additional river surveys are made, new sites are located which add somewhat to the total.[3]

Although we should not expect to use all potential water power, the range of possibility in storage is wide. Estimates made in 1936, based on gross head and 100 percent efficiency, showed 25,045,000 kilowatts available 95 percent of the time, allowance being made for storage reservoirs already built, and 82,180,000 kilowatts based on arithmetic mean flow.[4] In other words, for the streams included, the total potential power was estimated to be approximately 3.3 times the potential firm power, after allowance for the increase already brought about in potential firm power by storage existing in 1936.

The total of 25,045,000 kilowatts available 95 percent of the time at 100-percent efficiency is equivalent to 23,501,000 horsepower available 95 percent of the time at 70 percent efficiency.[5] But with allowance for probable effect of future storage, as envisioned in 1936, it was estimated that the potential power amounted to 42,753,000 horsepower available 90 percent of the time. The difference of 19,252,000 horsepower probably is explained mainly by allowance for future storage.

In view of the great variation in stream flow, the larger possibilities of water-power development lie in stream regulation, so as to permit adaptation of power production to variation in need for power. Such regulation is possible only through use of storage reservoirs. Effective control through storage requires basin-unit planning. Basin-unit development, being generally beyond the scope of private enterprise, is dependent on governmental action. And the effect of public policy on the arithmetic of water power is too significant to be ignored. For example, control at Norris Dam, in addition to providing a large stand-by plant, will double the prime power of eight dams below, in the Tennessee River. Professor Magnusson estimated that the high dam at the Grand Coulee, with upstream storage, would make available at Coulee an amount of firm power 6.8 times that available from natural stream flow; at dams between the Grand Coulee and the Snake River, an amount 2.86 times that available from natural stream flow; and at dams below the Snake River, 1.93 times that at natural stream flow.[6]

Efficiency

To some, the assumption of 70 percent efficiency may appear overcautious. The statement has been made by the Geological Survey that hydroelectric units recover "over 90 percent of the energy in falling water that drives the water wheels of a power plant." [7] In other words, the Geological Survey, in using the factor of 70 percent, assumed that, on the average, 20 percent of gross head would be lost for reasons other than the inefficiency of the turbine-generator unit itself. The Larue report in 1925 on the Colorado River likewise assumed 70 percent.[8] Professor Magnusson's estimates on Grand Coulee, however, assumed 80 percent efficiency.[9] About the same factor is reflected in T. V. A. estimates of 1936.[10] The effect of more clearly defined plans of coordinated development and operation, reflected in these latter estimates, may well be kept in mind.

National Importance of Water Power

At the outset, note that potential water power is mainly a potential source of electricity and is, therefore, broadly competitive with fuels in the production of electrical energy.[11] It is the only significant native source of energy in some regions and is a valuable supplementary source in others. In terms of the problem of conservation, water power is not reduced by use and is, therefore, a logical substitute for fuels in the generation of electricity. The amount of water power available in any year, however, has strict limits. Because of its very uneven regional distribution, its significance—in view of the economic limits of transmission of electrical energy—can be weighed more accurately on a regional basis. But a brief view of its national importance will facilitate the regional consideration.

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[2] Horton, A. H., U. S. Geological Survey, *Water Supply Paper 579* (1928), p. 116.

[3] U. S. Department of the Interior, *Potential Water Power in the United States* (mimeographed), August 20, 1936.

[4] *Ibid.*

[5] Conversion factor: 1 horsepower=0.746 kilowatt.

[6] Morgan, Arthur E., *Journal of the Western Society of Engineers*, vol. 41, No. 3 (June 1936), p. 116. Magnusson, Carl Edward, *Hydroelectric Power in Washington*, University of Washington, Engineering Experiment Station Series, Bulletin No. 78 (1935), pp. 23–25.

[7] Horton, *op. cit.*, p. 122.

[8] U. S. Geological Survey, *Water Supply Paper 556* (1925), p. 39.

[9] *Op. cit.*, p. 23, and table VII, facing p. 18.

[10] Tennessee Valley Authority, *The Unified Development of the Tennessee River System* (1936), p. 59. In the light of the formula, power in kilowatts=(H)(Q)(0.068), the estimates reflect a little over 80 percent assumed efficiency.

[11] Refer to ch. 5.

At the beginning of 1938, at all water-power plants having a capacity of 100 horsepower or more, there were installed water wheels aggregating 17,284,379 horsepower.[12] The Geological Survey considered at the beginning of 1936 that around one-fifth of our feasible potential water power had been developed.[13] The aggregate capacity of prime movers was estimated in 1935 at about 1.2 billions of horsepower.[14] These data indicate that water wheels for all water-power sites might have an aggregate capacity about 7 percent as great as the aggregate capacity of prime movers in 1935. Such percentage, although used at times, leads to an understatement of the importance of water power.

The central question is not capacity of prime movers; it is, on the contrary, the relative importance of water power as a source of energy. It is generally recognized that some prime movers are used much more than others. In the total of 1.2 billion cited, 965 million relate to motor vehicles, an amount 21.6 times the rated capacity of central electric stations at that time. Yet it is estimated that, in a period in which central electric stations produced 92 billion kilowatt-hours of electricity, automobiles produced energy equivalent to only 87 billion kilowatt-hours of electricity.[15]

Of the capacity of prime movers in the electric light and power industry, the annual (year-end) percentage water-driven in the period 1920–37 ranged from 25.5 to 28.4, the percentage being 28.3 at the end of 1937.[16] Of the installed water-wheel capacity at the end of 1937, about one-eighth was outside the utility industry.[17] Total capacity of installed water wheels at that time, therefore, was equal to somewhat over 32 percent of the capacity of all prime movers in the electric utility group. With the 1936 estimate that about one-fifth of the water power was developed, the conclusion would be reached that, at the present ratio of installation to site capacity, total capacity of water wheels for all feasible water power would be about 1.6 times the capacity of all prime movers in the electric utility industry at the end of 1937.

The Bureau of Mines estimates that our total use of energy in 1937 was equivalent to 24,183 trillion B. t. u.; water power, included in terms of prevailing use of fuels in generating power at central electric stations, is estimated to have supplied 849 trillion, or 3.51 percent of the total.[18] In terms of the estimate of 1936 that water power was approximately one-fifth developed, we might conclude that water power used at about the same efficiency as that of 1937 would in total produce annual energy equivalent to nearly 18 percent of the total energy used in 1937, which probably was greater than that of previous years except 1926 and 1929.[19]

Production of electricity by hydroelectric generators in electric utility plants in 1937 amounted to 43.7 billion kilowatt-hours.[20] Production of energy from water wheels outside the utility industry is not reported, but it is estimated as equivalent to 4.9 billion kilowatt-hours.[21] The total energy output of water wheels, therefore, is estimated to have been equivalent to 48.6 billion kilowatt-hours. The Federal Power Commission estimates feasible undeveloped power great enough to produce somewhat over 273 billion kilowatt-hours a year.[22] Presumably, existing water-power plants did not produce power as fully as their development and the available flow would permit. Therefore, the estimated total feasible energy output from water would exceed 322 billion. The estimated energy output of existing water-power plants was 48.6 billion, or 15.1 percent of 322 billion. Thus, water-power plants, estimated to have produced 3.51 percent of the total energy produced, are estimated to have produced something less than 15.1 percent of the feasible total output from water power. From these items follows the estimate that total feasible output from water power would at least exceed 23.3

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[12] Federal Power Commission, *Total Installed Capacity of Water Wheels in Water-Power Plants in the United States*, January 1, 1938.

[13] U. S. Department of the Interior, Geological Survey, *Total Capacity of Water Wheels at Water-Power Plants in the United States*, January 1, 1936.

[14] National Resources Committee, *Technological Trends and National Policy* (1937), p. 249.

[15] *Ibid.*, pp. 249, 252.

[16] Federal Power Commission, *Electric Power Statistics, 1937*, p. 15.

[17] Statement based on special compilation furnished by the Federal Power Commission. The utility classification used in the Commission's published report on installed capacity of water wheels, January 1, 1938, is not the same as that used for inclusion in *Electric Power Statistics, 1937*. Of the total of 17,284,379 horsepower reported for water-power plants having a capacity of 100 horsepower or more, the special compilation showed 2,131,787 horsepower not included in the utility group covered by the Commission in *Electric Power Statistics, 1937*.

[18] *Minerals Yearbook, 1938*, p. 703.

[19] Cf. *Minerals Yearbook, 1937*, pp. 807–8.

[20] Federal Power Commission, *Electric Power Statistics, 1937*, p. 3.

[21] Special compilation from the Federal Power Commission shows water wheels aggregating 2,131,787 horsepower not included in the group for which the Commission published electric output data for 1937. Capacity-use factor of 35 percent assumed. See table 6. It is recognized that part of this capacity is mechanical drive, not hydroelectric; but the more important part is in industrial hydroelectric plants.

[22] *Power Survey, 1938.* Pt. two, sec. II of this volume.

percent of the total energy produced in the form of fuels and water power in this country in 1937.

In view of the uncertainties sketched in the introductory pages, the estimates of feasible water power can be considered only useful approximations. Moreover, the Bureau of Mines' estimates of energy output from fuels and of the fuel equivalent from water power must be taken merely as the best comprehensive working approximations. In other words, exact evaluation of the importance of water power is impossible. But it looks as if feasible annual output from water power might be considered equal to more than one-fifth, possibly equal to one-fourth, of our largest past annual output of energy. Central stations are estimated to have used the equivalent of 1.42 pounds of coal per kilowatt-hour of electricity produced in 1937.[23] The estimated aggregate feasible potential output from water power, somewhat over 322 billion kilowatt-hours, would equal the energy obtainable, at present average central electric station performance, from about 225 or 230 million net tons of coal annually. Since the average steam plant displaced (or forestalled) by hydro is likely to be less efficient than the average central station, the equivalent coal tonnage may be larger.

If our use of energy continues to expand greatly, water power, being limited, could supply only an eventually declining portion of the energy. On the other hand, the expectation that our population might become stationary, or actually decline,[24] within a few decades, suggests that water power might come to hold its own or even to attain increased relative significance. This likelihood seems to hold especially for regions lacking, or facing an early lack of, mineral fuels.

TABLE 1.—*Potential water power in the United States* [1]

State and division	Available 90 percent of the time		Available 50 percent of the time	
	Horsepower (thousands)	Percent of United States total	Horsepower (thousands)	Percent of United States total
United States	42,753	100.00	57,184	100.00
New England	988	2.31	1,641	2.87
Middle Atlantic	4,895	11.45	6,242	10.92
East North Central	869	2.03	1,640	2.87
West North Central	1,172	2.74	1,884	3.29
South Atlantic	2,936	6.87	4,058	7.10
East South Central	2,620	6.13	3,761	6.58
West South Central	764	1.79	967	1.69
Mountain	10,775	25.20	13,031	22.79
Pacific	17,734	41.48	23,960	41.90
New England:				
Maine	524	1.23	806	1.41
New Hampshire	167	.39	293	.51
Vermont	115	.27	193	.34
Massachusetts	125	.29	211	.37
Rhode Island	5	.01	13	.02
Connecticut	52	.12	125	.22
Middle Atlantic:				
New York	4,296	10.05	5,184	9.07
New Jersey	32	.08	60	.11
Pennsylvania	567	1.33	998	1.75
East North Central:				
Ohio	31	.07	77	.14
Indiana	60	.14	159	.28
Illinois	214	.50	497	.87
Michigan	270	.63	400	.70
Wisconsin	294	.69	507	.89
West North Central:				
Minnesota	210	.49	388	.68
Iowa	96	.23	232	.41
Missouri	420	.98	676	1.18
North Dakota	61	.14	69	.12
South Dakota	211	.49	278	.49
Nebraska	101	.24	138	.24
Kansas	73	.17	103	.18
South Atlantic:				
Delaware	1.5	(2)	5	.01
Maryland and District of Columbia	200	.47	286	.50
Virginia	463	1.08	649	1.13
West Virginia	563	1.32	785	1.37
North Carolina	582	1.36	818	1.43
South Carolina	477	1.12	752	1.32
Georgia	622	1.45	729	1.27
Florida	27	.06	34	.06
East South Central:				
Kentucky	336	.79	543	.95
Tennessee	1,280	2.99	1,800	3.15
Alabama	880	2.06	1,280	2.24
Mississippi	124	.29	138	.24
West South Central:				
Arkansas	388	.91	518	.91
Louisiana	70	.16	74	.13
Oklahoma	126	.30	175	.31
Texas	180	.42	200	.35
Mountain:				
Montana	1,306	3.05	1,853	3.24
Idaho	2,706	6.33	3,688	6.45
Wyoming	571	1.34	838	1.47
Colorado	647	1.51	851	1.49
New Mexico	56	.13	124	.22
Arizona	3,710	8.68	3,810	6.66
Utah	1,500	3.51	1,590	2.78
Nevada	279	.65	277	.49
Pacific:				
Washington	8,768	20.51	12,021	21.02
Oregon	4,361	10.20	5,956	10.42
California	4,605	10.77	5,983	10.46

[1] U. S. Department of the Interior, *Potential Water Power in the United States* (mimeographed), Aug. 20, 1936. Computed from gross head, on the assumption of 70 percent efficiency, with allowance for future storage at known reservoir sites.

[2] Less than .005 percent.

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[23] *Minerals Yearbook, 1938*, p. 701.

[24] National Resources Committee, *The Problems of a Changing Population* (1938), pp. 6–8, 22–27.

TABLE 2.—*Capacity of installed water wheels in plants having 100 horsepower or more in the United States, 1921 and 1924–38* [1]

[Thousands of horsepower]

State and division	1921	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938
Continental United States	7,927	9,087	10,048	11,177	11,721	12,296	13,572	13,808	14,885	15,563	15,818	15,913	16,075	16,079	17,120	17,284
New England	1,311	1,387	1,399	1,485	1,535	1,556	1,654	1,643	1,898	1,939	1,947	2,001	2,006	1,994	2,005	2,004
Maine	450	473	477	497	526	537	539	541	579	613	613	613	616	603	600	593
New Hampshire	229	236	243	272	277	278	278	278	553	559	559	572	575	575	573	477
Vermont	130	168	168	193	200	200	260	260	202	202	202	192	192	192	194	274
Massachusetts	338	344	344	344	354	362	362	362	362	362	368	423	422	423	423	441
Rhode Island	30	30	30	30	30	30	30	30	30	30	30	29	29	29	28	28
Connecticut	134	136	136	148	148	148	184	172	171	172	174	175	173	172	186	191
Middle Atlantic	1,479	1,732	1,958	1,995	2,056	2,078	2,123	2,113	2,212	2,302	2,396	2,421	2,465	2,458	2,452	2,437
New York	1,292	1,543	1,714	1,750	1,757	1,779	1,814	1,805	1,904	1,892	1,900	1,885	1,885	1,879	1,872	1,858
New Jersey	17	19	19	19	19	19	19	18	18	17	17	17	17	17	17	17
Pennsylvania	170	170	226	226	280	280	291	291	291	392	478	520	563	562	563	562
East North Central	739	830	885	979	1,010	1,037	1,076	1,075	1,092	1,103	1,139	1,186	1,189	1,176	1,182	1,244
Ohio	29	30	30	29	30	30	30	30	25	21	22	23	23	24	24	23
Indiana	27	29	51	56	56	57	57	55	54	54	55	55	55	55	55	53
Illinois	85	85	87	94	94	94	94	95	96	94	94	88	88	93	92	85
Michigan	267	282	305	352	355	378	378	379	399	414	444	464	477	483	500	580
Wisconsin	331	404	413	446	474	477	517	517	519	520	524	555	546	521	512	503
West North Central	444	460	515	525	533	542	555	551	567	765	767	762	750	746	844	840
Minnesota	205	212	263	267	275	276	293	287	286	287	287	287	272	272	269	268
Iowa	173	177	177	179	180	184	182	181	182	182	184	183	183	183	183	178
Missouri	18	18	20	21	21	21	21	23	37	235	235	235	235	235	235	236
North Dakota [2]	------	------	------	------	------	------	------	------	------	------	------	------	------	0	0	------
South Dakota	18	18	19	20	20	20	20	19	20	20	20	20	20	20	20	20
Nebraska	15	20	21	21	21	24	24	24	25	24	24	24	24	24	124	124
Kansas	15	15	14	17	17	17	16	16	16	16	16	13	16	13	13	14
South Atlantic	1,082	1,301	1,594	1,702	1,841	1,967	2,595	2,657	2,918	2,968	2,979	3,036	3,173	3,218	3,201	3,224
Delaware	3	3	3	1	1	1	1	1	1	1	1	1	1	1	2	1
Maryland	7	7	7	38	38	38	416	416	416	416	416	409	404	405	405	404
District of Columbia	1	1	1	1	1	6	6	6	6	6	6	6	6	6	6	6
Virginia	104	110	118	139	138	141	140	126	135	153	155	152	154	156	157	151
West Virginia	15	15	15	21	91	91	91	89	87	87	87	87	227	269	269	272
North Carolina	330	432	535	538	543	644	814	947	954	961	971	971	980	980	957	947
South Carolina	330	358	507	514	571	574	574	574	816	810	810	811	811	811	813	837
Georgia	286	369	400	441	449	463	544	473	482	512	512	578	569	569	572	584
Florida	7	7	9	9	9	8	9	25	22	21	21	20	20	20	20	22
East South Central	241	341	392	745	868	966	1,119	1,169	1,364	1,364	1,364	1,298	1,303	1,303	1,526	1,563
Kentucky	1	1	1	34	34	142	142	145	145	145	145	145	145	145	145	141
Tennessee	127	128	166	174	174	177	177	179	288	288	288	288	291	291	423	423
Alabama	113	211	224	537	659	646	799	845	931	931	931	865	867	867	958	999
Mississippi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West South Central	16	17	31	32	32	44	47	49	49	134	150	150	150	145	149	150
Arkansas	1	1	16	16	16	16	16	16	16	95	95	95	95	95	95	95
Louisiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oklahoma	2	2	2	2	2	2	2	3	3	3	2	2	2	2	2	2
Texas	13	14	14	14	15	27	29	31	31	37	53	53	53	48	52	53
Mountain	827	881	937	981	1,030	1,118	1,140	1,185	1,217	1,216	1,212	1,209	1,190	1,199	1,728	1,758
Montana	344	345	360	376	376	378	393	419	429	428	429	428	428	429	429	431
Idaho	224	271	299	319	320	355	358	358	357	355	348	348	342	355	357	364
Wyoming	8	8	8	10	10	17	17	10	25	25	23	23	23	23	24	24
Colorado	92	88	91	95	96	95	98	98	98	98	102	101	102	99	103	105
New Mexico	1	1	1	2	2	2	2	2	2	1	2	2	2	2	2	2
Arizona	39	39	49	49	59	104	104	120	137	137	137	137	137	133	193	196
Utah	106	115	115	115	153	153	154	156	157	158	158	156	144	141	142	156
Nevada	13	14	14	14	13	13	14	14	14	14	14	14	13	13	478	481
Pacific	1,789	2,139	2,336	2,733	2,815	2,988	3,263	3,365	3,568	3,772	3,865	3,848	3,851	3,842	4,033	4,065
Washington	454	480	561	656	657	707	747	766	892	1,011	1,053	1,037	1,037	1,037	1,227	1,254
Oregon	185	207	244	242	242	289	289	299	354	354	364	364	363	360	361	367
California	1,149	1,452	1,531	1,835	1,917	1,993	2,227	2,301	2,321	2,407	2,448	2,447	2,450	2,444	2,445	2,443

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[1] Source: U. S. Department of the Interior, Geological Survey, except for 1938, for which data are from the Federal Power Commission. Data are as of the beginning of the year after 1925. National and regional totals taken before rounding; hence, an occasional slight discrepancy.

[2] Less than 500 horsepower; none in 1937 and 1938.

Table 3.—*Production of electric energy in the United States in 1937* [1]

[Thousands of kilowatt-hours]

State and division	Total	Hydro	Fuel
United States	121 049, 630	43, 702, 000	77, 347, 630
New England	7, 841, 748	3, 234, 233	4, 607, 515
Maine	857, 376	808, 812	48, 564
New Hampshire	762, 211	705, 642	56, 569
Vermont	642, 396	641, 281	1, 115
Massachusetts	3, 169, 578	691, 250	2, 478, 328
Rhode Island	648, 910	11, 403	637, 507
Connecticut	1, 761, 277	375, 845	1, 385, 432
Middle Atlantic	30, 837, 046	8, 190, 478	22, 646, 568
New York	16, 561, 945	6, 147, 273	10, 414, 672
New Jersey	3, 810, 076	29, 447	3, 780, 629
Pennsylvania	10, 465, 025	2, 013, 758	8, 451, 267
East North Central	28, 404, 496	2, 312, 304	26, 092, 192
Ohio	8, 173, 693	37, 301	8, 136, 392
Indiana	3, 812, 777	148, 893	3, 663, 884
Illinois	8, 048, 810	249, 562	7, 799, 248
Michigan	5, 694, 618	987, 575	4, 707, 043
Wisconsin	2, 674, 598	888. 973	1, 785, 625
West North Central	7, 771, 445	1, 955, 008	5, 816, 437
Minnesota	1, 661, 790	583, 176	1, 078, 614
Iowa	1, 908, 717	724, 399	1, 184. 318
Missouri	1, 872, 464	579, 912	1, 292, 552
North Dakota	200, 431	0	200, 431
South Dakota	144, 288	9, 387	134, 901
Nebraska	710, 929	36, 458	674, 471
Kansas	1, 272, 826	21, 676	1, 251, 150
South Atlantic	14, 132, 766	7, 158, 182	6, 974, 584
Delaware	10, 841	0	10, 841
Maryland	2, 276, 012	1, 625, 604	650, 408
District of Columbia	693, 865	12, 003	681, 862
Virginia	1, 745, 179	433, 514	1, 311, 665
West Virginia	2, 906, 328	364, 546	2, 541, 782
North Carolina	2, 085, 574	1, 671, 520	414, 064
South Carolina	1, 746. 856	1, 614, 597	132, 259
Georgia	1, 742, 160	1, 387, 785	354, 375
Florida	925, 951	48, 613	877, 338
East South Central	5, 137, 399	3, 538, 679	1, 598, 720
Kentucky	888, 439	308, 195	580, 244
Tennessee	1, 404, 371	823, 298	581, 073
Alabama	2, 768, 069	2, 407, 186	360, 883
Mississippi	76, 520	0	76, 520
West South Central	6, 387, 784	261, 215	6, 126, 569
Arkansas	277, 691	151, 401	126, 290
Louisiana	1, 668, 391	0	1, 668, 391
Oklahoma	1, 098, 459	1. 671	1, 096, 788
Texas	3, 343, 243	108, 143	3, 235, 100
Mountain	5, 777, 876	4, 388, 338	1, 389, 538
Montana	1, 319, 637	1, 297, 345	22, 292
Idaho	972, 212	971, 232	980
Wyoming	131, 139	41, 782	89, 357
Colorado	721, 482	219, 732	501, 750
New Mexico	255, 378	1, 695	253, 683
Arizona	717, 825	421, 013	296, 812
Utah	507, 415	293, 696	213, 719
Nevada	1, 152, 788	1, 141, 843	10, 945
Pacific	14, 759, 070	12, 663, 563	2, 095, 507
Washington	3, 734, 715	3, 290, 544	444, 171
Oregon	1, 392, 177	1, 007, 815	384, 362
California	9, 632, 178	8, 365, 204	1, 266, 974

[1] Source: Federal Power Commission, Electric Power Statistics, 1937. Production for strictly private use not included; but electric railways, electrified sections of steam railways, and miscellaneous Federal and other plants serving Government or public are included.

Table 4.—*Electric generator capacity of utility power and light plants at the end of 1937* [1]

[Kilowatts]

State and division	Tota	Fuel plants	Hydroelectric plants
United States	37, 032, 112	26, 557, 768	10, 474. 344
New England	2, 920, 400	2, 070, 643	849, 757
Maine	232, 973	57, 040	175, 933
New Hampshire	299, 659	62, 402	237, 257
Vermont	187, 347	12, 900	174, 447
Massachusetts	1, 322, 055	1, 155, 050	167, 005
Rhode Island	244, 671	241, 421	3, 250
Connecticut	633, 695	541, 830	91, 865
Middle Atlantic	9, 178, 278	7, 670, 664	1, 507, 614
New York	5, 219, 446	4, 111, 417	1, 108, 029
New Jersey	1. 071, 732	1, 066, 832	4, 900
Pennsylvania	2, 887, 100	2, 492, 415	394, 685
East North Central	8, 183, 159	7, 538, 887	644, 272
Ohio	2, 194, 215	2, 181, 215	13, 000
Indiana	1, 039, 366	1, 004, 866	34, 500
Illinois	2, 337, 052	2, 286, 622	50, 430
Michigan	1, 696, 197	1, 391, 105	305, 092
Wisconsin	916, 329	675, 079	241, 250
West North Central	2, 852, 026	2, 363, 337	488, 689
Minnesota	620, 366	463, 865	156, 501
Iowa	619, 294	491, 514	127, 780
Missouri	745, 310	594, 765	150, 545
North Dakota	72, 208	72, 208	0
South Dakota	72, 944	68, 844	4, 100
Nebraska	297, 770	257, 489	40, 281
Kansas	424, 134	414, 652	9, 482
South Atlantic	4, 479, 768	2, 517, 620	1, 962, 148
Delaware	34, 675	34, 675	0
Maryland	594, 906	323, 521	271, 385
District of Columbia	222, 400	220, 000	2, 400
Virginia	474, 438	377, 216	97, 222
West Virginia	674, 847	583, 942	90, 905
North Carolina	992, 875	341, 089	651, 786
South Carolina	632, 882	132, 342	500, 540
Georgia	475, 479	141, 962	333, 517
Florida	377, 266	362, 873	14, 393
East South Central	1, 849, 147	755, 417	1, 093, 730
Kentucky	337, 250	232, 100	105, 150
Tennessee	530, 356	211, 506	318, 850
Alabama	917, 307	247, 577	669, 730
Mississippi	64, 234	64, 234	0

[1] Source: Federal Power Commission, *Electric Power Statistics, 1937*. Includes not only public utility light and power plants, privately owned and publicly owned, but also electric railway, electrified sections of steam railroads, miscellaneous Federal, State, and municipal plants not strictly in utility field, and that portion of private manufacturing plant capacity devoted to public use. Generator capacity for strictly private use not included.

TABLE 4.—*Electric generator capacity of utility power and light plants at the end of 1937*—Continued

TABLE 4.—*Electric generator capacity of utility power and light plants at the end of 1937*—Continued

State and division	Total	Fuel plants	Hydroelectric plants
West South Central	1,765,579	1,664,040	101,539
Arkansas	155,811	89,106	66,705
Louisiana	314,447	314,447	0
Oklahoma	331,334	329,715	1,619
Texas	963,987	930,772	33,215
Mountain	1,661,733	501,726	1,160,007
Montana	276,146	10,646	265,500
Idaho	258,432	2,882	255,550
Wyoming	52,029	36,199	15,830
Colorado	253,090	188,731	64,359
New Mexico	96,115	95,201	914
Arizona	225,537	98,487	127,050
Utah	156,740	65,061	91,679
Nevada	343,644	4,519	339,125
Pacific	4,142,022	1,475,434	2,666,588
Washington	1,009,085	215,127	793,958
Oregon	360,259	182,018	178,241
California	2,772,678	1,078,289	1,694,389

TABLE 5.—*Percentage distribution of potential water power and of other items, United States, by region and State* [1]

State and division	Potential water power available 90 percent of the time [2]	Population 1930 [3]	Land area [3]	Horsepower in manufacturing and mining 1929 [3]	Installed water wheels end of 1937 [4]	Electric generator capacity of public utilities, end of 1937 [5]			Power output of utility plants, 1937 [5]			Estimated power output, all water wheels in 1937 [6]	Coal reserves, B. t. u. basis [7]
						Total	Fuel	Hydro	Total	Fuel	Hydro		
United States, total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
New England	2.31	6.7	2.08	9.51	11.59	7.89	7.80	8.11	6.48	5.96	7.40	10.04	....
Maine	1.23	.6	1.01	1.37	3.43	.63	.21	1.68	.71	.06	1.85	3.25	....
New Hampshire	.39	.4	.30	.81	2.76	.81	.23	2.27	.03	.07	1.61	1.98	....
Vermont	.27	.3	.31	.40	1.58	.51	.05	1.67	.53	[8]	1.47	1.43	....
Massachusetts	.29	3.5	.27	4.17	2.55	3.57	4.35	1.59	2.62	3.20	1.58	2.29	....
Rhode Island	.01	.6	.04	.93	.16	.66	.91	.03	.54	.82	.03	.13	....
Connecticut	.12	1.3	.16	1.83	1.10	1.71	2.04	.88	1.46	1.79	.86	.96	....
Middle Atlantic	11.45	21.4	3.36	27.81	14.10	24.78	28.88	14.39	25.47	29.28	18.74	18.25	4.77
New York	10.05	10.3	1.60	8.19	10.75	14.09	15.48	10.58	13.68	13.46	14.06	13.99	....
New Jersey	.08	3.3	.25	3.40	.10	2.89	4.02	.05	3.15	4.89	.07	.08	....
Pennsylvania	1.33	7.8	1.51	16.22	3.25	7.80	9.38	3.77	8.65	10.93	4.61	4.18	4.77
East North Central	2.03	20.6	8.26	27.60	7.20	22.10	28.39	6.15	23.47	33.73	5.29	5.91	14.03
Ohio	.07	5.4	1.37	9.06	.14	5.93	8.21	.12	6.75	10.52	.09	.10	3.76
Indiana	.14	2.6	1.21	4.06	.31	2.81	3.78	.33	3.15	4.74	.31	.33	2.12
Illinois	.50	6.2	1.88	6.43	.49	6.31	8.61	.48	6.65	10.08	.57	.58	8.08
Michigan	.63	3.9	1.93	5.46	3.36	4.58	5.24	2.91	4.70	6.09	2.26	2.50	.08
Wisconsin	.69	2.4	1.86	2.59	2.91	2.47	2.54	2.30	2.21	2.31	2.03	2.40	....
West North Central	2.74	10.8	17.18	5.48	4.86	7.70	8.90	4.67	6.42	7.52	4.47	4.36	17.80
Minnesota	.49	2.1	2.72	1.62	1.55	1.68	1.75	1.49	1.37	1.39	1.33	1.45	....
Iowa	.23	2.0	1.87	.84	1.03	1.67	1.85	1.22	1.58	1.53	1.66	1.50	1.17
Missouri	.98	3.0	2.31	1.75	1.37	2.01	2.24	1.44	1.55	1.67	1.33	1.19	3.42
North Dakota	.14	.6	2.36	.17	....	.19	.27	....	.17	.26	....	....	11.98
South Dakota	.49	.6	2.58		.12	.20	.26	.04	.12	.17	.02	.08	.02
Nebraska	.21	1.1	2.58	.36	.71	.80	.97	.38	.59	.87	.08	.09	....
Kansas	.17	1.5	2.75	.74	.08	1.15	1.56	.09	1.05	1.62	.05	.05	1.21
South Atlantic	6.87	12.9	9.05	10.55	18.65	12.10	9.48	18.73	11.68	9.02	16.38	17.34	7.25
Delaware	[8]	.2	.07	[9] .32	.01	.09	.13	....	.01	.01	....	.01	[8]
Maryland	.47	1.3	.33	1.38	2.31	1.61	1.22	2.59	1.88	.84	3.72	3.35	.31
District of Columbia		.4	[8]	[9]	.03	.60	.83	.02	.57	.88	.03	.03	....
Virginia	1.08	2.0	1.35	1.50	.87	1.28	1.42	.93	1.44	1.70	.99	1.02	.86
West Virginia	1.32	1.4	.81	2.62	1.58	1.82	2.20	.87	2.40	3.29	.83	1.41	6.03
North Carolina	1.36	2.6	1.64	1.71	5.48	2.68	1.28	6.22	1.72	.54	3.82	4.92	[8]
South Carolina	1.12	1.4	1.03	1.08	4.84	1.71	.50	4.78	1.44	.17	3.69	3.52	....
Georgia	1.45	2.4	1.97	1.34	3.38	1.28	.53	3.18	1.41	.46	3.18	2.95	.04
Florida	.06	1.2	1.81	.60	.13	1.02	1.37	.14	.76	1.13	.11	.10	....
East South Central	6.13	8.1	6.04	5.34	9.04	4.99	2.84	10.44	4.24	2.07	8.10	7.84	8.72
Kentucky	.79	2.1	1.35	1.33	.82	.91	.87	1.00	.73	.75	.71	.64	4.97
Tennessee	2.99	2.1	1.40	1.37	2.44	1.43	.80	3.04	1.16	.75	1.88	2.19	1.03
Alabama	2.06	2.2	1.72	2.09	5.78	2.48	.93	6.39	2.29	.47	5.51	5.01	2.72
Mississippi	.29	1.6	1.56	.54	....	.17	.24	....	.06	.10	....	....	....

Footnotes at end of table on following page.

TABLE 5.—*Percentage distribution of potential water power and of other items, United States, by region and State*—Continued

State and division	Potential water power available 90 percent of the time	Population 1930	Land area	Horsepower in manufacturing and mining 1929	Installed water wheels end of 1937	Electric generator capacity of public utilities, end of 1937			Power output of utility plants, 1937			Estimated power output, all water wheels in 1937	Coal reserves, B. t. u basis
						Total	Fuel	Hydro	Total	Fuel	Hydro		
West South Central	1.79	9.9	14.45	3.92	.87	4.77	6.27	.97	5.28	7.92	.60	.54	3.08
Arkansas	.91	1.5	1.77	.52	.55	.42	.34	.64	.23	.16	.35	.31	.06
Louisiana	.16	1.7	1.53	.95	---------	.85	1.18	---------	1.38	2.16	---------	---------	---------
Oklahoma	.30	2.0	2.33	.65	.01	.89	1.24	.02	.91	1.42	(8)	(8)	2.24
Texas	.42	4.7	8.82	1.80	.31	2.60	3.50	.32	2.76	4.18	.25	.23	.78
Mountain	25.20	3.0	28.89	3.82	10.17	4.49	1.89	11.07	4.77	1.80	10.04	9.10	[10] 42.39
Montana	3.05	.4	4.91	.80	2.49	.75	.04	2.53	1.09	.03	2.97	2.67	8.19
Idaho	6.33	.4	2.80	.34	2.10	.70	.01	2.44	.80	(8)	2.22	2.02	[10] .02
Wyoming	1.34	.2	3.28	.19	.14	.14	.14	.15	.11	.12	.10	.09	17.95
Colorado	1.51	.8	3.49	.70	.61	.68	.71	.61	.60	.65	.50	.48	11.63
New Mexico	.13	.3	4.12	.23	.01	.26	.36	.01	.21	.33	(8)	(8)	.82
Arizona	8.68	.4	3.83	.76	1.13	.61	.37	1.21	.59	.38	.97	.87	[10] .04
Utah	3.51	.4	2.76	.60	.90	.42	.24	.88	.42	.28	.67	.62	3.74
Nevada	.65	.1	3.69	.20	2.78	.93	.02	3.24	.95	.01	2.61	2.35	---------
Pacific	41.48	6.7	10.70	5.98	23.52	11.18	5.56	25.46	12.19	2.71	28.98	26.62	[10] 1.96
Washington	20.51	1.3	2.25	1.71	7.26	2.72	.81	7.58	3.09	.57	7.53	6.99	1.94
Oregon	10.20	.8	3.22	.85	2.12	.97	.69	1.70	1.15	.50	2.31	2.36	[10] .02
California	10.77	4.6	5.23	3.42	14.14	7.49	4.06	16.18	7.96	1.64	19.14	17.27	

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[1] Alaska and insular possessions not included. Occasional slight discrepancy due to rounding.

[2] Repeated for comparative purposes, from table 1.

[3] Population percentages as computed by the Bureau of the Census. *Statistical Abstract of the United States, 1936*, p. 5. Percentages of land areas and of horsepower in manufacturing and mining computed from census data.

[4] Based on data given for beginning of 1938, table 2.

[5] Based on data given in tables 3 and 4.

[6] Amounts in table 6.

[7] Based on B. t. u. equivalent of coal reserves, as estimated by the Geological Survey, except allocation explained in footnote 10.

[8] Less than 0.005 percent.

[9] In reported data, the District of Columbia is included with Delaware.

[10] In B. t. u. estimates furnished (see footnote 7), Idaho and Arizona are combined with Oregon and California, the 4 States combined having only 0.08 percent of the coal reserves, B. t. u. basis. This fraction was allocated here on the basis of reserves in those States as reported by the Geological Survey for the end of 1928.

TABLE 6.—*Estimates of total energy output at existing water power plants, of feasible additional output, and of total feasible output*

[Millions of kilowatt-hours]

State and division	Estimated total output, water-power plants existing, end of 1937 [1]	Estimated feasible additional annual output [2]	Estimated minimum [3] feasible total annual output
United States	48,580	273,377	321,957
New England	4,876	4,509	9,385
Maine	1,581	1,609	3,190
New Hampshire	961	940	1,901
Vermont	693	1,365	2,058
Massachusetts	1,110	137	1,247
Rhode Island	64	0	64
Connecticut	467	458	925
Middle Atlantic	8,868	14,239	23,107
New York	6,798	10,893	17,691
New Jersey	40	362	402
Pennsylvania	2,030	2,984	5,014

[1] To hydro output shown in table 3, estimates have been added for output of waterwheels not covered by the reports of the Federal Power Commission on production of electrical energy. Capacity of such water wheels reported by the Power Commission. Electrical output (or equivalent, for mechanical drive) estimated on the basis of an assumed 35 percent capacity-use factor.

[2] Estimates by Federal Power Commission. Pt. two, sec. II, chap. 1, of this report.

[3] Minimum, because it is recognized that existing installations were not operated at either plant or site capacity.

TABLE 6.—*Estimates of total energy output at existing water power plants, of feasible additional output, and of total feasible output*—Continued

Regions and States	Estimated total output, water-power plants existing, end of 1937	Estimated feasible additional annual output	Estimated minimum feasible total annual output
East North Central	2,870	3,069	5,939
Ohio	51	84	135
Indiana	160	477	637
Illinois	282	517	799
Michigan	1,212	1,015	2,227
Wisconsin	1,165	976	2,141
West North Central	2,119	2,690	4,809
Minnesota	706	989	1,695
Iowa	727	516	1,243
Missouri	580	814	1,394
North Dakota	0	0	0
South Dakota	39	55	94
Nebraska	42	316	358
Kansas	25	0	25
South Atlantic	8,422	22,424	30,846
Delaware	2	0	2
Maryland	1,629	1,834	3,463
District of Columbia	16	270	286
Virginia	493	4,482	4.975
West Virginia	699	7,122	7,821
North Carolina	2,389	3,898	6,287

TABLE 6.—*Estimates of total energy output at existing water power plants, of feasible additional output, and of total feasible output*—Continued

Regions and States	Estimated total output water-power plants existing, end of 1937	Estimated feasible additional annual output	Estimated minimum feasible total annual output
South Carolina	1,711	2,201	3,912
Georgia	1,434	2,617	4,051
Florida	49	0	49
East South Central	3,806	19,511	23,317
Kentucky	309	2,856	3,165
Tennessee	1,063	11,711	12,777
Alabama	2,434	4,286	6,720
Mississippi	0	655	655
West South Central	263	5,927	6,190
Arkansas	151	2,255	2,406
Louisiana	0	1,064	1,064
Oklahoma	2	1,559	1,561
Texas	110	1,049	1,159

TABLE 6.—*Estimates of total energy output at existing water power plants, of feasible additional output, and of total feasible output*—Continued

Regions and States	Estimated total output water-power plants existing, end of 1937	Estimated feasible additional annual output	Estimated minimum feasible total annual output
Mountain	4,425	58,844	63,269
Montana	1,299	10,283	11,582
Idaho	982	19,909	20,891
Wyoming	43	2,964	3,007
Colorado	235	2,301	2,536
New Mexico	2	250	252
Arizona	422	12,316	12,738
Utah	299	8,257	8,556
Nevada	1,143	2,564	3,707
Pacific	12,931	142,164	155,095
Washington	3,395	72,709	76,104
Oregon	1,146	34,487	35,633
California	8,390	34,968	43,358

CHAPTER 3.—THE REGIONAL PATTERN OF WATER POWER

Little water power is used directly at the power site. Commonly, stream energy is converted into electrical energy and transmitted to points of use. Technical limits of transmission are hardly defined. The central question regarding transmission of power for ordinary uses, however, is not how far some power might be transmitted regardless of cost. It is, on the other hand, how far power may be transmitted without a cost reaching uneconomic levels. If a given area must have power, it may choose between generating near at hand or obtaining power over transmission lines from other areas. Delivered cost of power transmitted some distance cannot, in a free market, long exceed the alternative cost of generating by fuel or hydro closer at hand. But, in the long run, industry cannot either buy or generate in a given area if it may move into areas of cheaper power without incurring disadvantages offsetting the reduction in cost of power.

No specific economic limit of transmission can be stated. But limits narrow enough to necessitate regional regard for water power are obvious enough. Dr. Karl T. Compton, president of Massachusetts Institute of Technology, although pointing out the advantages of interconnection over far wider areas, said in recent times that, with methods then existent, electric power could be distributed economically over an area not more than about 250 miles from the generating station.[25] J. D. Ross, late Administrator at Bonneville, said more recently that the practical transmission distance for alternating current for very large blocks of power is about 300 miles.[26] In view of the rough relation between number of miles and number of thousands of volts desirable for distance transmission, this broad economic limit is reflected in the fact that at the end of 1936 there were in the country only 3,033 miles of transmission lines carrying 220,000 volts or more.[27] It is to be noted, however, that the upper voltage has risen from 220,000 to 285,000 in very recent years.

Both the possibility of expansion in the economic limits of transmission and the economies of interconnection of electric power plants are recognized for later consideration; but regard for experience makes it wise to consider our water power in its regional setting.

It is essential to observe the caution that the breakdown by State and region is, in general, only for convenience in attaining a closer view of the probable significance of water power. The present interstate and interregional movements of fuels and electrical energy are recognized. And, with the advance of interconnection among generating stations, the significance of future hydro developments, especially the greater ones, must be viewed in the light of a rather long economic reach of transmission. That reach has extended in recent years; and it seems likely to extend further, even in terms of alternating current. If direct current

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[25] *Edison Electric Institute Bulletin*, vol. 5, No. 1 (January 1937), p. 5.

[26] *Scientific American*, December 1938, p. 305.

[27] Edison Electric Institute, *Statistical Bulletin No. 5*, 1937, p. 9.

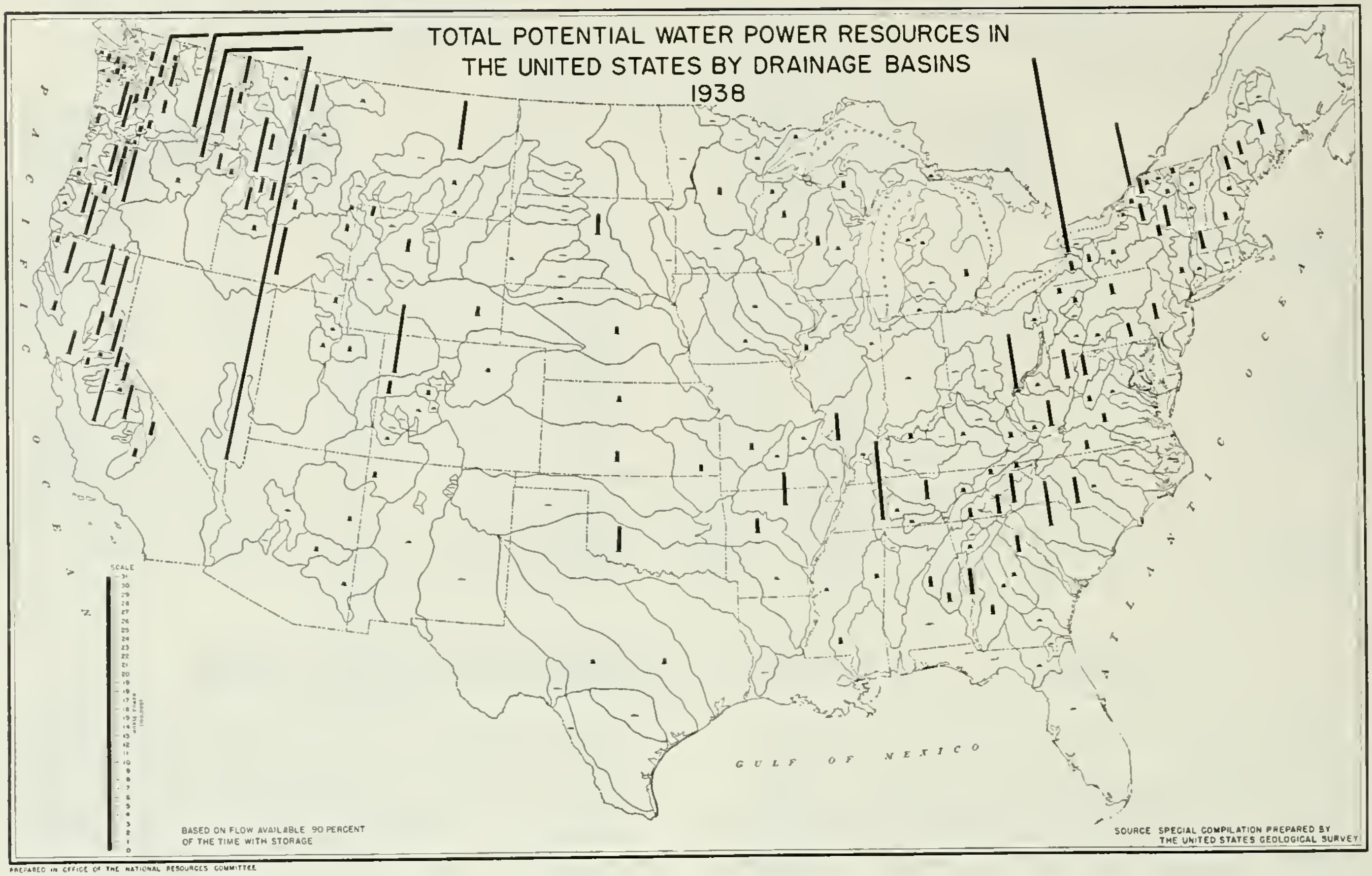
TOTAL POTENTIAL WATER POWER RESOURCES IN THE UNITED STATES BY DRAINAGE BASINS 1938
PACIFIC OCEAN
GULF OF MEXICO
ATLANTIC OCEAN
SCALE
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
BASED ON FLOW AVAILABLE 90 PERCENT OF THE TIME WITH STORAGE
SOURCE SPECIAL COMPILATION PREPARED BY THE UNITED STATES GEOLOGICAL SURVEY
PREPARED IN OFFICE OF THE NATIONAL RESOURCES COMMITTEE

FIGURE 1.

transmission is adopted for the long reach with large blocks of power, the limits conceived with reference to alternating current may be of little relevance.

Estimates of potential water power are presented in table 1, which shows also the allocation among the States and geographic divisions. It should be noted that these are estimates of total potential water power, including that at developed sites. Estimates of feasible undeveloped power are shown in table 6. Reference should be made also to tables 2 to 5.[28] Figures 1 and 2 show, respectively, potential water power (available 90 percent of the time) and capacity of installed water wheels, the former according to drainage basins and the latter according to location.

New England

New England, with 9.5 percent of the horsepower in manufacturing and mining in 1929 and 6.7 percent of the population in 1930, has only 2 or 3 percent of the water power and negligible deposits of mineral fuel. In spite of this low percentage of water power, New England has more than one-ninth of the capacity of water wheels. That is, in terms of the condition prevailing nationally, New England has advanced far in the use of water power. Water wheels appeared there, of course, in the very early industrial history of the country.[29] Relative importance of hydro in utility output of electricity is shown in figure 3.

At the end of 1937 about 29 percent of the generator capacity of New England plants producing electricity for public use was water-driven, a proportion only slightly different from the national percentage; but, whereas the hydroelectric output of the utility group constituted only 36.1 percent of their total nationally, it was 41.2 percent of the New England total. Moreover, 35.8 percent of the water-wheel capacity in New England was outside the public-utility classification, although nationally only 12.3 percent was outside the utility industry.[30] A substantial part of the capacity outside the utility group is used for mechanical drive rather than for generation of electricity.

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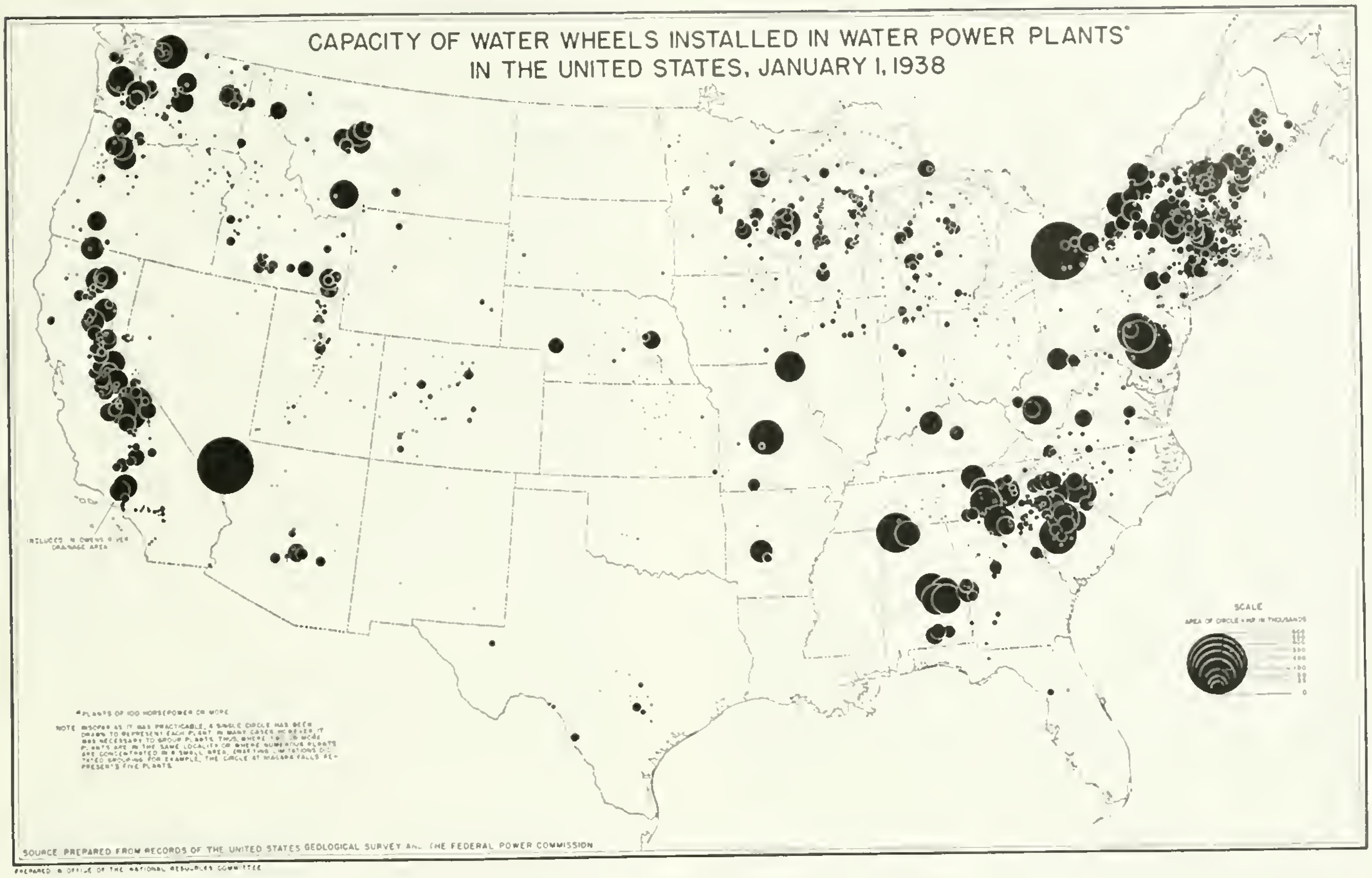
[28] Other data used in succeeding pages, unless specifically noted otherwise, are from, or based on, official Government reports. References should be made especially to secs. I and II above and to secs. I and II of pt. two, below.

[29] For illustration of the early strategic significance of water power in New England, see Shlakman, Vera, *Economic History of a Factory Town: A Study of Chicopee, Massachusetts,* Smith College Studies in History, vol. XX, Nos. 1–4 (October 1934–July 1935), pp. 11–47.

[30] Based on table 2 and special data furnished by the Federal Power Commission.


CAPACITY OF WATER WHEELS INSTALLED IN WATER POWER PLANTS*
IN THE UNITED STATES, JANUARY 1, 1938

*PLANTS OF 100 HORSEPOWER OR MORE

NOTE: INSOFAR AS IT WAS PRACTICABLE, A SINGLE CIRCLE HAS BEEN DRAWN TO REPRESENT EACH PLANT. IN MANY CASES HOWEVER IT WAS NECESSARY TO GROUP PLANTS. THUS, WHERE TWO OR MORE PLANTS ARE IN THE SAME LOCALITY OR WHERE NUMEROUS PLANTS ARE CONCENTRATED IN A SMALL AREA, DRAFTING LIMITATIONS DICTATED GROUPING. FOR EXAMPLE, THE CIRCLE AT NIAGARA FALLS REPRESENTS FIVE PLANTS.

SOURCE: PREPARED FROM RECORDS OF THE UNITED STATES GEOLOGICAL SURVEY AND THE FEDERAL POWER COMMISSION

PREPARED IN OFFICE OF THE NATIONAL RESOURCES COMMITTEE

INCLUDES OWENS RIVER DRAINAGE AREA
SCALE
AREA OF CIRCLE = HP IN THOUSANDS
500
400
100
0

FIGURE 2.

With its great industrial and metropolitan power loads, New England has to draw heavily on outside fuel resources. Total receipts of coal in New England in 1937 aggregated 17.8 million net tons, and sales of distillate and residual fuel oil there in 1936 totaled over 36.9 million barrels.[31]

Soon after the World War, the problem of additional power for New England received earnest consideration. Some fairly large water power and many small power possibilities were known to exist; but it was realized that even the best feasible use of New England water power would be too limited to provide the relief needed.[32] Moreover, Maine, which has an important share of New England's potential water power, has a legal ban (with some exceptions) on the use of her water power for loads outside the State.[33] The possibility of power for New England from Niagara and the international section of the St. Lawrence was being considered, but distance seemed a major hurdle in terms of the stage of development existing in transmission at that time. Even in 1929, the Brookings Institution, after extensive analysis, although conceding its eventual development, doubted the practical economic availability of St. Lawrence power except in terms of some future prospect for great power-consuming industries at or near the river.[34] At the end of 1928 (i. e., just preceding the report of the Brookings Institution) there were in this country no utility transmission lines rated above 220,000 volts.[35] Subsequently, the Boulder-Los Angeles line of 285,000 volts appeared, extending 266 miles, power from Boulder going 60 to 100 miles farther after the step-down from this very high voltage. The Power Authority of the State of New York, meanwhile, is convinced that its estimates on various proportions of power at distances 50, 100, and 200 miles from the power sites and under different load-factor assumptions are distinctly in favor of the hydro development on the St. Lawrence.[36] In view of the significant development in transmission,[37] and with recognition of the abundant potential firm power in the St. Lawrence, consideration of St. Lawrence power for part of the New England load within a few years seems more plausible than it did a few years ago.

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[31] *Minerals Yearbook, 1938*, pp. 698, 885.

[32] Murray, W. S., and others, *A Supervisor System for the Region Between Boston and Washington*, U. S. Department of the Interior, Geological Survey, Professional Paper 123 (1921). Northeastern Super Power Committee, *Super Power Studies for the Northeast Section of the United States*, (1924). Main, Charles T., Harriman, Henry I., and Jackson, Dugald C., "Power Requirements and Sources of Supply of New England," *Journal of the Boston Society of Civil Engineers*, vol. XI, No. 5 (May 1924), pp. 193–227.

[33] Federal Power Commission, *National Power Survey, Interim Report*, Power Series No. 1 (1935), pp. 35, 46. Revised Statutes of Maine, 1930, ch. 68, p. 1108.

[34] Moulton, Harold G., Morgan, Charles S., and Lee, Adah L., *The St. Lawrence Navigation and Power Project* (1929), pp. 226–27.

[35] Edison Electric Institute, *Statistical Bulletin No. 5*, 1937, p. 9.

[36] 75th Congress, 2d Session, *House Document No. 52*, pp. 6, 17–18.

Higher fuel costs appear likely in New England, as elsewhere. Rise in cost of fuel oil is especially likely because of increased use, pressure of exploitation on known reserves, domestic regulation, and the heightened tension of international rivalries for oil. New England's main recourse, in such contingency, must be either more abundant hydro power or heavier draft on coal. Meanwhile, reflections of comparative maturity, if not of actual stress, in that region are seen in the relatively slow growth of population and actual loss of manufacturing wage earners in important New England industrial areas.[38] In the cotton textile industry the number of active spindles in New England increased until 1921; but from 1900 to 1921 the increase of number in the cotton-growing States was more than twice as great. From 1921 through 1938 (reporting year ended July 31) the number in New England declined by about 12,469,000, while the number in the cotton-growing States increased by approximately 2,419,000.[39] Far the larger part of the spindles in place outside New England are in the Carolinas, Georgia, and Alabama, where great use is made of water power.[40] But a notable fact about New England manufactures in the post-war period has been the great increase in the use of power equipment (except in Vermont) and an increasing relative dependence on motors driven by purchased energy.[41] And there was an increase of about 53 percent in water-wheel capacity in New England from 1921 to 1938. For an area devoid of native fuel resources and having only limited water power, the larger stake in industrial power equipment means an intensified problem of industrial power.

Middle Atlantic Division

The Middle Atlantic division, comprising the States of New York, New Jersey, and Pennsylvania, had 21.4 percent of the national population in 1930. That division in 1929 had 27.8 percent of the horsepower in manufacturing, mines, and quarries. Since only about 3.4 percent of the land area of the country is in those States, the relatively high density of population and industry is obvious. Of the estimated total potential water power, the Middle Atlantic division has 11.5 percent. This percentage is comparatively high in terms of land area, but it is comparatively low in terms of population and industry. Moreover, it should be noted that this proportion of the Nation's water power is reached only by the inclusion of additional power from more complete use of our allotment of the international waters of the Niagara River and our probable share of power on the international section of the St. Lawrence. The latter is not legally accessible until agreement is reached with Canada. About half of the undeveloped power in this division is in these two streams. Regarding these great sources, what was said above with respect to New England applies broadly. Earlier doubts relating to distance seem to be sufficiently reduced by recent transmission developments to permit reconsideration of Niagara and the St. Lawrence as possible sources of additional hydro power for important loads in the Middle Atlantic section. In addition, water power in portions of Maryland, Virginia, and West Virginia may be kept in mind, particularly with reference to Pennsylvania loads.

Of the total water-wheel capacity in the Middle Atlantic division, nearly 88 percent is in public-utility plants. At the end of 1937, water-driven generators constituted a little less than one-sixth of the capacity of utility power plants. Although for the country generally hydroelectric output constituted more than 36 percent of the electricity for public use in 1937, the corresponding percentage in the Middle Atlantic States was only 28. That region produced 25.5 percent of the Nation's electricity for public use in 1927, but it produced only 18.7 percent of the national output of hydroelectric plants of public utilities.

This highly industrialized area must depend on fuel for the larger part of its power. Its fuel resources are mainly the coal beds of Pennsylvania. Its industrial fuel resources are mainly the bituminous coal beds in the western half of Pennsylvania. Heavy draft, however, is made on coal from more southward areas, and substantial use is made of oil.

At the end of 1937 the total capacity of water wheels in plants having more than 100 horsepower each was 1,858,000 horsepower in New York. Judged by the approximations in table 6, use was made of only about 38 percent of the feasible potential water power of that State in 1937. The total production of electricity at utility hydroelectric plants was somewhat over 6.1 billion kilowatt-hours in 1937; other water wheels being included, the total output was the equivalent of about 6.8 billion. The undeveloped water power of New York, estimated to be great enough for an output of nearly 10.9 billion, is in large part in the western portion of the State. There are, of course, important loads in western and middle New York, but the larger present requirements for power are on or near the eastern seaboard. Hence the great significance of the search for an acceptable plan to reach eastward with the large potential base power in the western part of the State.

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[37] National Resources Committee, *Technological Trends and National Policy* (1937), pp. 269 ff., especially 278–80.

[38] See McLaughlin, Glenn E., *Growth of American Manufacturing Areas*, Bureau of Business Research, University of Pittsburgh (1938), Charts 11, 27.

[39] U. S. Department of Commerce, Bureau of the Census, *Cotton Production and Distribution, Season of 1937–38*, Bulletin 175, pp. 23, 27. The national total declined by less than one-third of the peak number; the New England total declined by more than two-thirds of its peak.

[40] *Ibid.*, p. 34.

[41] Fifteenth Census of the United States: 1930, *Manufactures, 1929*, vol. III. Refer to summaries for the respective New England States.

Nearly 63 percent of the utility output of electricity in New York in 1937 was fuel-generated. Both the greater load and the greater proportionate dependence on fuel are in the eastern part of the State. Most of the fuel used for generation of power in 1937 was coal.[42] In 1929 Pennsylvania supplied a little more than half of the coal received by rail in New York. Close to one-third, received by tidewater, was not classified by origin in the available data, but West Virginia originated 56 percent of all tidewater coal in 1929. Comparison of 1929 data with 1917 data shows increasing reach of New York to fuel beds lying south of Pennsylvania.[43]

Pennsylvania has estimated water power aggregating 567,000 horsepower available 90 percent of the time. At the end of 1937 the capacity of installed water wheels was 562,000 horsepower. The estimated feasible potential is indicated by table 6 to be about 2½ times the use of water power in 1937, if not more.

The most significant hydroelectric plants in Pennsylvania are in the eastern part of the State, interconnected with large fuel plants. The centers of western Pennsylvania having large power requirements are near the coal beds. If considered in terms of power alone, extensive developments of the western Pennsylvania rivers might well be doubted for the near future. It must be remembered, however, that disastrous floods of recent years, as well as grave problems of stream pollution, not to speak of the additional problem of cheap navigation, have focused considerable interest on the development of those rivers. The Pennsylvania State Planning Board has dramatically shown the gravity of the flood problem in the Pittsburgh region and favors prompt planning of adequate flood-control works. In view of the relative cheapness of power from steam plants "under prevailing conditions," the board does not recommend any hydroelectric projects for the western Pennsylvania section.[44] One need not overlook, however, that prevailing conditions, as regards stream flow, would be greatly altered by works of the kind approved by the board. For example, it is reported that rainfall in the Tygart Basin was less than 50 percent of normal in October 1938 but that storage in Tygart Reservoir provided about 80 percent of the flow in the upper Monongahela during that month. Moreover, at the date of the announcement, November 18, it was said that storage in Tygart Reservoir was sufficient to maintain the flow until December 15.[45] If 80 percent of the flow was due to that storage project, one may proceed by simple arithmetic to the conclusion that, during the dry month, flow in the upper Monongahela with that storage was five times what it would have been without it.

With regard to the Middle Atlantic section as a whole, one cannot escape the fact that, in view of the location of the coal beds and of the huge amount of water required for condensing,[46] large plants at or near the mine mouth are possible only in western Pennsylvania and to a much more limited extent in the central Pennsylvania bituminous fields and the anthracite fields of the east. In most of the densely industrial Middle Atlantic division, fuel must bear a considerable freight charge. The increasing comparative exhaustion of the better beds of coal and the attempts at price control in the bituminous coal industry and in the oil and gas industry suggest increased fuel cost and greater inducement to the development of water power in the Middle Atlantic States.

East North Central

This division, composed of Ohio, Indiana, Illinois, Michigan, and Wisconsin, had nearly the same proportion as the Middle Atlantic of national population in 1930 and of horsepower in manufacturing and mining combined in 1929. The estimated water power there is only a little more than one-sixth that of the Middle Atlantic division, although the land area is close to 2½ times as large.

The available water power in the East North Central division is estimated at 869,000 horsepower available 90 percent of the time and 1,640,000 horsepower available 50 percent of the time. Spread between the two estimates, being so much greater than that in areas in which the obvious presence of much greater power has led to more examination of storage possibilities, suggests that storage might increase the lower figure considerably. The future importance to this division of any comprehensive water control measures in either the Ohio Valley or portions of the Mississippi may be noted.

Estimated feasible undeveloped power adequate for an annual output of 3.1 billion kilowatt-hours is indicated for this region; hydroelectric production in that area in 1937, including an allowance for water wheels outside utility and public plants, is estimated at about 2.9 billion. Far the larger part of the hydro production of the East North Central group is in Michigan and Wisconsin, which also have the larger part of the undeveloped power of that division.

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[42] Federal Power Commission, *Electric Power Statistics, 1937,* pp. 19–26.

[43] Fritz, Wilbert G., and Veenstra, Theodore A., *Regional Shifts in the Bituminous Coal Industry* (Bureau of Business Research, University of Pittsburgh, 1935), pp. 50–52.

[44] Pennsylvania State Planning Board, *Drainage Basin Study of Pennsylvania* (1937), pt. 3, pp. 121–23.

[45] *Pittsburgh Press*, November 18, 1938.

[46] For example, the Duquesne Light Co. (Pittsburgh and vicinity) reports the use of 600 million gallons a day, six times as much as is used by the whole population in Pittsburgh. Advertisement, *Pittsburgh Post-Gazette*, January 6, 1939.

Ohio and Indiana have very limited potential water power. For Ohio, it seems quite conceivable that the rather large undeveloped water power of West Virginia may eventually have considerable significance. And Kentucky power possibilities may have a bearing on the requirements of Indiana.

Wisconsin is without known fuel resources. At the end of 1937, utility generator capacity in Wisconsin aggregated 916,329 kilowatts, of which 241,250, or more than 26 percent, was hydro. Total capacity of installed water wheels in Wisconsin declined by about 52,000 horsepower from the beginning of 1934 to the end of 1937. No doubt some significant water power may come from developments aimed at steam control, both on streams in the Great Lakes Basin and in the upper Mississippi Basin.[47] The State has the advantage of comparative cheapness of fuel and abundance of condensing water on Lake Michigan, near the major industrial loads; but further development of water power is expected when the somewhat extended fuel plant capacity is sufficiently taxed to call for additional power for peak purposes.[48] Feasible undeveloped water power in Wisconsin is estimated to be sufficient for an annual output of 976 million kilowatt-hours. The estimated total output in 1937, including industrial, was equivalent to somewhat less than 1.2 billion.

Michigan has some coal, lying southward of Saginaw Bay, but produces at a disadvantage. Her annual production in the period 1934–36 averaged 625,000 tons; in 1937, it was 561,000 tons.[49] But Michigan public-utility plants alone used over 2.5 million tons in 1937 for power production. Hydro production of utility plants in 1937 approximated 988 million kilowatt-hours, or about 17 percent of their output. The total energy output of all water wheels in Michigan is estimated at more than 1.2 billion. Feasible undeveloped power of more than a billion kilowatt-hours annually is estimated. Coal for use in Michigan is drawn largely from West Virginia and eastern Kentucky fields.[50] The haulage necessary to obtain fuel suggests pressure in the direction of available water power. A significant increase in water-wheel capacity in recent years tends to indicate such pressure.

Illinois is estimated to have 214,000 horsepower available 90 percent of the time and 497,000 half of the time. The spread suggests possible advance of the lower figure by storage. Production of all water wheels in the state in 1937 amounted to about 282 million kilowatt-hours. A feasible additional total of over 500 million is estimated. Early utilization of the remainder, if development of waters were dependent wholly on power, might be doubted, for Illinois has coal reserves amounting to approximately 198 billion tons and annual production of 40 to 60 million tons. Problems of flood control, stream pollution, and navigation, however, may lead to substantial joint-product or byproduct power. As regards the Chicago metropolitan area, the factor of transmission cost, which has to be considered with reference to water power, is already encountered in the fuel-generated power supply, as we may note in the tie to a great fuel plant on the Illinois River.[51]

South Atlantic Division

This division includes the seaboard States from Delaware to Florida, inclusive, and the inland State of West Virginia. It had 12.9 percent of the population in 1930 and 10.6 percent of the combined horsepower in manufacturing and mining in 1929. With 9 percent of the land area, it has around 7 percent of the water power. Thus, relative to either population, industry, or land area, water power is somewhat low.

Water wheels in the South Atlantic division, including those outside the utility industry, are estimated to have produced the equivalent of about 8.4 billion kilowatt-hours in 1937. A feasible output from undeveloped water power of more than 22.4 billion kilowatt-hours is estimated. Of 3,224,000 horsepower of installed water wheels at the end of 1937, plants not included in the utility classification had 552,600 horsepower, the larger part of this industrial class being in West Virginia and North Carolina.[52]

Hydroelectric generators constituted close to 44 percent of utility capacity and supplied more than half of all electricity produced for public use in the South Atlantic division in 1937. In 1932, 44.8 percent of the utility generating capacity was hydro and, with depression emphasis on hydro operations, 61 percent of the production was hydro. The total utility output was nearly 9.5 billion kilowatt-hours in 1932; less than 37 million came from publicly-owned hydro plants.[53]

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[47] National Resources Committee, *Drainage Basin Problems and Programs* (1937 revision), pp. 27–31.

[48] National Resources Board. *Inventory of the Water Resources of the Great Lakes, St. Lawrence River and Red River of the North Drainage Area* (1935), pp. 31–32.

[49] *Minerals Yearbook, 1938*, pp. 696, 708.

[50] Fritz and Veenstra, *op. cit.*, pp. 60–61.

[51] Federal Power Commission, *National Power Survey, Interim Report*, Power Series No. 1 (1935), map facing p. 6.

[52] Data from the Federal Power Commission.

[53] Census of Electrical Industries: 1932, *Central Electric Light and Power Stations*, pp. 32, 36, 57, 59.

Population in that area, in round numbers, was 5.9 million in 1870; 10.4 million in 1900; and 15.8 million in 1930. Agriculturally, the region is mostly old and long ago settled; these great gains are in a significant measure due to industrial and commercial growth. That growth, very much associated with textiles and tobacco, has also important showings in chemicals, paper, and other lines.[54]

From 1900 to 1930, when the percentage increases of population in the great Middle Atlantic and East North Central divisions were, respectively, 69.9 and 58.3 percent, the population of the South Atlantic division increased 51.2 percent. From the end of 1926 to the end of 1937, generating capacity of the light and power industry increased nationally by 51 percent; in that period generating capacity in the South Atlantic area increased by 58 percent. Nationally, the number of consumers increased by 34 percent. In the South Atlantic area the number increased by 56 percent.[55] In that period the total reported capacity of installed water wheels of the South Atlantic group, including industrial plants, increased 75 percent. In short, the area has shown sharp increase in the use of water power.[56]

Before we consider the several States, it is well to guard against any appearance of overemphasizing the dependence of those States on their own power resources. The transmission interconnection of the southeast is notable.[57] Private water-power development in the Piedmont and mountain sections of the Carolinas and Georgia and both public and private development in Alabama and Tennessee are in the area of an important interconnected network, the character of which, of course, is still in the making.

It is essential also to observe that there are pressing problems of flood control, stream pollution, and public water supply in this southeastern area. Power possibilities are large in the designs necessary to deal with the water-control problems.[58]

Florida and Delaware have negligible water power. The other States will be examined briefly in the order of the magnitude of available water power.

Georgia has 622,000 horsepower available 90 percent of the time and about one-sixth more available half of the time. The capacity of all installed water wheels in Georgia at the end of 1937 was nearly 584,000 horsepower, 96.5 percent of this being in utility plants. The hydro capacity of utilities comprised seven-tenths of their total capacity and supplied nearly eight-tenths of their production in 1937. Having negligible fuel resources and negligible coal output, Georgia might be expected to lean on the coal resources of her neighbors—Alabama and Tennessee. The coal used by electric utilities in Georgia in 1937, however, aggregated only 32,529 tons; fuel oil, amounting to 261,464 barrels, was the fuel equivalent of about 65,000 tons of coal; natural gas, almost 3.6 billions of cubic feet, equaled around 157,000 tons of coal.[59] In other words, on a thermal basis, 85 to 90 percent of the fuel used by utilities in that State was oil and gas. Most of this use of natural gas has come about since the Census of Electrical Industries was taken in 1932. A gas pipe line from Louisiana extends eastward of Atlanta.

Output of all water wheels in Georgia in 1937 is estimated to have been equivalent to somewhat over 1.4 billion kilowatt-hours. Feasible output from undeveloped water power is estimated at about 2.6 billion. Thus, the physical latitude for great increase of water power is obvious.

North Carolina, according to the Geological Survey, had in 1936 a total of 582,000 horsepower available 90 percent of the time and 818,000 available half of the time. Feasible annual output from undeveloped water power in that State is estimated at nearly 3.9 billion kilowatt-hours. The estimated total output of water wheels in 1937 was less than 2.4 billion.

The population of North Carolina increased by 24 percent from 1920 to 1930; this gain was far above the 12.9 percent in the South Atlantic division and the 16.1 percent in the Nation as a whole. From 1919 to 1929, the average number of wage earners in manufactures in the State rose from 158,000 to 210,000 and the horsepower in manufacturing rose from 550,000 to 840,000. Growth in the cotton textile industry and in the tobacco industry has been of great importance in North Carolina in recent decades. Total water-wheel capacity almost tripled from 1921 to 1935, nearly all being privately developed. In other words, the evidence of growing use of power has not been wanting. North Carolina has relatively minor coal reserves and negligible coal production. There is appearance, therefore, of incentive for continuing the development of water power, quite aside from the further urge introduced in connection with public problems of stream control of that region.

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[54] Cf. "The Industrial South," *Fortune*, vol. XVIII, No. 5 (November 1938), p. 45.

[55] Based on data from Edison Electric Institute, *Statistical Bulletin No. 4* January 1937, pp. 36, 38, and *Statistical Bulletin No. 5* (April 1938) pp. 7, 11.

[56] The rise of the cotton textile industry in the south, in comparison with that of New England, was at first centered particularly in the Carolinas and Georgia. The great rise of the tobacco industry also has been especially significant there. Bengtson, Nels A., and Van Royen, Willem, *Fundamentals of Economic Geography* (1936), pp. 628, 723.

[57] Federal Power Commission, *National Power Survey, Interim Report*, Power Series No. 1 (1935), map facing p. 6.

[58] National Resources Committee, *Drainage Basin Problems and Programs*, (1937 Revision), pp. 19–23.

[59] Fuel used: Federal Power Commission, *Electric Power Statistics, 1937*, pp. 20–26. Assumed for conversion: 4 barrels of oil or 23,000 cubic feet of natural gas equal 1 ton of coal. U. S. Bureau of the Census, *Central Electric Light and Power Stations*, 1932, p. 21.

In West Virginia, feasible annual output of water power is estimated at 7.8 billion kilowatt-hours. Total output of water wheels in that State in 1937 is estimated at only 699 million. Water-wheel capacity amounted to only 272,000 horsepower at the end of 1937, and more than two-thirds of this total appeared after 1934. Water wheels outside the reported utility group aggregated 146,100 horsepower at the end of 1937. Only one-eighth of the production of electricity by utilities in West Virginia was from hydro plants in 1937.

West Virginia has huge coal reserves and huge production, having risen into first position among the States in coal output. And yet a large private hydro plant, first reflected in the water-wheel data for the end of 1934, must have been constructed in the depth of the depression, when the coal industry was desperate for markets. Whether that circumstance represents a break of development in West Virginia is not certain. But that there are larger quantities of water power available for the future is certain. The possible significance of West Virginia water power to some of the Ohio loads has been mentioned above. If considered wholly on a power basis, the prospect of water power in West Virginia must be viewed against the backdrop of cheap fuel. But again (February 1939), flood devastation in West Virginia draws attention to the need of water control measures; and it is hardly in line with economy to forget the power possibilities of such controls.

South Carolina has feasible undeveloped water power estimated to be sufficient for an output of 2.2 billion kilowatt-hours annually. In 1937, the estimated total output of all water wheels in the State was 1.7 billion kilowatt-hours.

South Carolina had water-wheel capacity aggregating 837,000 horsepower at the end of 1937. The comparable total in 1921 was 330,000 horsepower. Approximately 95 percent of this capacity was in the plants of public utilities. Over 92 percent of the production of electricity by the utility groups in South Carolina in 1937 was from hydroelectric generators.

Population in South Carolina increased only 3.3 percent from 1920 to 1930. From 1919 to 1929, however, the horsepower in manufacturing increased from 395,000 to 527,000. Capacity of installed water wheels, aggregating 330,000 horsepower in 1921, has exceeded 800,000 horsepower since 1930. Growth in power and in power requirements in South Carolina may be seen clearly. Without native fuel resources, South Carolina is likely to see more marked development of water power.

Virginia's feasible undeveloped water power is estimated to be sufficient for an output of 4.5 billion kilowatt-hours annually. The power output of all water wheels in this State in 1937 is estimated at 493 million kilowatt-hours.

Virginia's growth in recent years has not been rapid, but there has been growth. The State has no very important coal reserves except in the far southwest extremity. The neighboring State of West Virginia has abundant coal, and its coal fields are the source of a tremendous flow of coal eastward, especially to tidewater at Hampton Roads. The water-wheel capacity in Virginia declined somewhat after 1928, but there was some increase afterward, the total at the end of 1937 being 151,000 in comparison with 104,000 at the end of 1921. Approximately one-fourth of the utility output in Virginia in 1937 was hydro. The Census showed a little over one-third in 1932.

East South Central

This division includes the States of Kentucky, Tennessee, Alabama, and Mississippi. These States together embrace approximately 6 percent of the land area of the country; in 1930 the area included 8.1 percent of the national population. It has somewhat over 6 percent of the potential water power, as estimated in 1936, and has about 7 percent of the undeveloped power. Of the generator capacity of public utilities in the country, about 5 percent was located in the East South Central division at the end of 1937, and only 4.24 percent of the utility production of electricity took place in that area. The aggregate horsepower in manufacturing, mines, and quarries in 1929 constituted about 5 percent of the national total. Thus the area is noticeably below the national average in per capita water power, industrial horsepower, electric generator capacity, and output of electricity. The estimated total energy output of water wheels in this region in 1937 was 3.8 billion kilowatt-hours. The estimated feasible output from undeveloped water power is 19.5 billion.

In considering the water power of the East South Central division it is well to recognize at the outset both the extensive transmission network of the southeast and the great public project in the Tennessee Valley. The extensive network signifies the importance of the developed interchange of power between Tennessee and Alabama and the States to the east (in the South Atlantic division). The public project of multiple-purpose character reflects a species of coordinated basin-wide development which not only adds greatly to the total hydro available but also gives added significance to hydro as a source for base power.

Of the generator capacity of electric utilities in the East South Central Division, 59.1 percent at the end of

1937 was water driven; the comparable national percentage was 28.3. Of the production of electricity at central stations for which data are shown in table 3, 68.9 was from hydroelectric generators; the comparable national percentage was 36.1.

Capacity of T. V. A. is becoming of importance in that area; but it should be noted that in 1932 approximately half of the capacity of prime movers in the power and light industry of that area was water-driven. Generator capacity driven by water in 1932 aggregated nearly 722,000 kilowatts; practically all of the utility hydroelectric output in 1932 was from privately owned utility plants.[60] This great development by private enterprise had taken place in a region which has more than 15 percent of the national bituminous coal reserves in only 6 percent of the land area; and it took place in the three coal States, Mississippi having no hydro. At the end of 1937 the total hydroelectric generator capacity of the utility group in the East South Central division, publicly owned and privately owned, was 1,093,730 kilowatts. Hydro generators having an aggregate capacity of 348,000 kilowatts had been installed in T. V. A. plants at that time, 100,000 in Tennessee (Norris) and 248,000 in Alabama (Wilson and Wheeler). Of the estimated additional feasible energy output from water power in the East South Central division, only about one-third is in approved T. V. A. projects.[61]

Kentucky was estimated in 1936 to have potential water power amounting to 336 thousand horsepower available 90 percent of the time and 543 thousand horsepower available 50 percent of the time. But the State also has huge coal reserves and a large coal production. The capacity of installed water wheels at the end of 1937 aggregated only 141,000 horsepower, this total being about the same as that at the end of 1927. Almost 100 percent of this capacity is in utility plants; there is no hydroelectric capacity in publicly owned plants in Kentucky. Hydroelectric generators comprised 31.2 percent of the generator capacity of utilities in Kentucky at the end of 1937, and 34.7 percent of the production of electricity for public use was from hydro plants. The estimated total energy output from water wheels in Kentucky in 1937 was about 309 million kilowatt-hours. Estimated feasible output from undeveloped water power is close to 2.9 billion. One of the projects of T. V. A. (Gilbertsville) is near Paducah; and, distance being considered, it seems possible that some Kentucky power requirements might eventually be met from other T. V. A. works. On the other hand, some of the potential water power of Kentucky might eventually have a bearing on requirements in southern Ohio and Indiana.

Tennessee water power was estimated in 1936 to be 1,280,000 horsepower available 90 percent of the time and 1,800,000 available 50 percent of the time. The total water-wheel capacity in Tennessee at the end of 1937 was 423,000 horsepower, about 75 percent of which was in utility plants. Hydroelectric generators at the end of 1937 comprised more than 60 percent of the capacity of electric utility plants in Tennessee and provided about 59 percent of their production. The Census of Electrical Industries in 1932 showed relatively minor capacity in public plants in Tennessee; nevertheless, hydro capacity at that time constituted practically half of the total utility capacity. In other words, the development to 1932 was almost wholly private. Even in 1935 the Power Commission showed no large public plant completed there.[62] At the end of 1937, however, the total utility hydro generator capacity in Tennessee was 318,850 kilowatts, of which the T. V. A. plant at Norris Dam had 100,000 kilowatts. Use of this capacity at Norris, however, is planned only in terms of Norris Lake as primarily a storage reservoir. Generators there will be used when water is being released for downstream maintenance of water levels.[63] Installations were made at Pickwick Landing in 1938.

Feasible output from undeveloped water power in Tennessee is estimated at approximately 11.7 billion kilowatt-hours annually. The estimated total energy output of all water wheels in 1937 was equivalent to about 1.1 billion kilowatt-hours.

Tennessee has bituminous coal reserves exceeding 25 billion tons, and there are far greater reserves to the north, in Kentucky, and to the south, in Alabama. The maximum annual coal production of Tennessee was 7,121,000 tons in 1910.[64] During the World War period coal production in Tennessee exceeded 6 million tons per year. In 1937 the total was 5,292,000 tons. The coal fields of Tennessee sprawl across the State in a northeast-southwest direction not far west of Knoxville and Chattanooga. In 1935 there were seven large hydroelectric plants in or near the Tennessee coal belt; although all were interconnected, only two were in direct combination with fuel plants.[65] Norris Dam (in the coal area) was not completed at that time. In other words, private industry had developed these large plants in or very near the coal fields of Tennessee, presumably with only the purpose of power production, and without the great advantage of storage and controlled release of water provided in the T. V. A. design.

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[60] Census of Electrical Industries: 1932, *Central Electric Light and Power Stations*, pp. 32, 58–59.

[61] Refer to table A, sheet 7, and table B in *Power Survey, 1938*, by the Federal Power Commission, pt. two, sec. 11 of this volume.

[62] Federal Power Commission, *National Power Survey, Interim Report*, Power Series No. 1 (1935), map facing p. 6.

[63] Tennessee-Cumberland Basin Committee, *Drainage Basin Committee Report for the Tennessee and Cumberland Basins* (1937), p. 7; *Annual Report of the Tennessee Valley Authority for the Fiscal Year Ended June 30, 1934*, p. 9.

[64] *Minerals Yearbook, 1938*, p. 708.

[65] Federal Power Commission, *National Power Survey, Interim Report*, Power Series No. 1 (1935), map facing p. 6.

In Alabama the potential water power available 90 percent of the time was estimated in 1936 at 880,000 horsepower; that available 50 percent of the time at 1,280,000. As shown by the census of electrical industries, 64 percent of the generator capacity of electric power utilities in Alabama in 1932 was hydroelectric. None of this was in publicly owned plants. At the end of 1937, 73 percent of the generator capacity was hydro and nearly 87 percent of the production during that year was hydroelectric. Utility hydroelectric capacity reported for Alabama at that time amounted to 669,730 kilowatts; of this, 248,000 belonged to the T. V. A.

Feasible water power in Alabama is estimated to be sufficient for annual production of 6.7 billion kilowatt-hours. The actual production in 1937 was about 2.4 billion. In viewing the probable future development one must remember, of course, that Alabama has 67 billion tons of bituminous coal reserves and a large coal production. In the predepression period production ran as high as 21 million tons a year. Since 1931 the level has been only 8 to 9 million tons. The larger part of this decline presumably is related to depressed conditions. But undoubtedly natural gas and fuel oil in large quantities have been substituted for coal in former markets of Alabama coal. At any rate, so far as concerns the use of coal in the production of electricity, one must observe that in 1932, under private business enterprise, nearly two-thirds of the generator capacity was hydro.

Mississippi, with an estimated potential of 124,000 horsepower 90 percent of the time, reports no water-power plant with as much as 100 horsepower. The State has no coal, and its total production of electricity in 1937 amounted to only 76.5 million kilowatt-hours. The extension of transmission lines of T. V. A. plants into Mississippi may lead one to suppose that the production in Mississippi represents a depressed condition of public utilities there. Actually, the total annual output in Mississippi in the period 1926 to 1936, inclusive, ranged from a little more than 50 million kilowatt-hours to somewhat more than 68 million.[66] The relatively low output in Mississippi, of course, is related to the high-capacity ties with plants (privately owned) in Tennessee, Louisiana, and Alabama.

West North Central

Comprised of seven States, the West North Central division covers more than 17 percent of the land area of the country and had 10.8 percent of the population in 1930. Of the generator capacity of utilities, this division had 7.7 percent at the end of 1937. At the same time, it had only 4.7 percent of the hydroelectric capacity of utilities and only 4.9 percent of the total national capacity of water wheels. It has only about 3 percent of the potential water power.

Thus the West North Central division, in terms of both size and population, is lacking in electric power, in hydro capacity, and in potential water power. Very large segments of this region are characterized by scarcity or complete lack of fuel resources, and scarcity of water resources characterizes most of it. The area reported 13,297,000 people in 1930 and had experienced a population growth of 6 percent from 1920 to 1930.

Missouri has large bituminous coal reserves in the western part of the State, and St. Louis and other load centers in the eastern part have ready access to Illinois coal. In spite of this relatively favorable position with respect to coal, Missouri showed an increase of 198,000 horsepower in installed water wheels in 1931, the increase being made by privately owned utilities.

Iowa also has substantial coal reserves; and her eastern centers, like those of Missouri, have ready access to Illinois coal. Nevertheless, a fifth of the State's utility generator capacity is hydro, and 38 percent of the utility output of electricity in 1937 was from hydroelectric generators. The hydro capacity is largely in the eastern part of the State; the great plant at Keokuk, constituting a major part of the total, is connected to the St. Louis district. Although the Keokuk plant is connected northwestward with Iowa points and northeastward with Illinois points, its higher capacity interconnections reach southward to the St. Louis metropolitan area. There has been a slight decline in Iowa's water-wheel capacity in recent years, but the decline in coal production has been vastly more significant.

Kansas and the Dakotas have negligible water power. Kansas has coal reserves somewhat larger than those of Iowa, located in the eastern part of the State. Western Kansas is closer to Colorado coal. North Dakota has huge lignite reserves. South Dakota has a small share of the lignite beds, in the northwestern part of the State.

One-fourth of Minnesota's utility generator capacity at the end of 1937 was hydro, and over 35 percent of the utility output of electricity in 1937 was from hydroelectric generators. Estimated use of water power in Minnesota in 1937 was equivalent to 706 million kilowatt-hours. A feasible additional total of 989 million is estimated. The total water-wheel capacity in Minnesota, however, was noticeably less at the end of 1937 than it was at the end of 1928. It may be well to note that the handicap related to the remoteness of Minnesota from large fuel reserves is in part, at least, offset by the need of returning ore boats for back load. A very considerable portion of Minnesota's fuel supply arrives by lake boats, being drawn from the Appalachian fields.[67]

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[66] Edison Electric Institute, *Statistical Bulletin No. 4* (1937), p. 37, and *Statistical Bulletin No. 5* (1938), p. 29.

The estimated energy output of water wheels in Nebraska in 1937 was about 42 million kilowatt-hours. Feasible output from undeveloped water power is estimated by the Federal Power Commission at 316 million, in the Platte Basin.

A program for irrigation and power, under what is referred to as Nebraska's little T. V. A., embraces the idea of a widely interconnected system, with fuel plants included. The plan has been broadened to include the purchase of the privately owned utilities affected. In the discussion related to this effort of Nebraska, attention has been drawn not merely to the problem of dealing with the private utilities but also to need of assurances (*a*) to farmers, regarding water for irrigation, (*b*) to consumers, regarding probable rates, and (*c*) to cities, regarding their possible loss of tax revenue.

This effort of Nebraska represents the most advanced State action yet occurring in the development of water resources. The effectiveness within Nebraska of regulation of the Platte will depend appreciably on headwater controls in Wyoming and Colorado; and the total extent and character of controls exercised by these three States bear on the regulation of the Missouri and, hence, of the Mississippi. The plan definitely illustrates both the possibility of State action and the necessity of interstate cooperation and Federal coordination.

In viewing the energy resources and energy requirements of the West North Central division, one must keep in mind the material difference between the four States in the western tier and the three in the eastern tier.

The shortage of water and the ravages of erosion in much of the western part of this division are well recognized.[68] Although many people have left the area and many more may have to do so, nevertheless we have to face the obvious fact that we have not developed social techniques for moving large populations or for facilitating their voluntary migration. Adaptations of agricultural methods, with special regard for plant growth that will cover and bind the soil, may offer substantial promise in the "dust bowl." But integral with any plan of salvation for the region is control of water resources so that the area may make the most of the relatively scant and irregular water supply. Flood control is a major need for some portions of the area. Irrigation is a major need for large portions, often in the same areas which have major flood problems. The rainfall is so irregular that successful dealing with flood problems necessitates storage relatively large in comparison with the annual rainfall. The dry seasons are of such length and often of such severity that a consistent irrigation program is impossible without large storage which will not merely retard runoff in the wet seasons but will also hold the water for later use. In such a program, production of power must often be controlled by the primary purpose of irrigation; but the large controlled release during the dry seasons may provide substantial power.

In the eastern part of the West North Central division there are likewise large sections faced with flood-control problems. In that area, however, the accompanying problem, instead of irrigation, is stream pollution. Moreover, whether for good or ill, the development of affairs has been such as to hook with these other water problems the provision of navigation facilities in the larger rivers. Thus, although the requirements are different, the eastern tier of States, like the western, has need of significant works that provide water storage and controlled release of water. One other major difference, however, should be noted: release of water in the western tier of these States is necessarily tied to the agricultural seasons; on the other hand, release of water in the eastern tier is not so tied to the agricultural requirement and, therefore, may be more nearly regularized throughout the year. Such regularized release holds promise of firm water power enough to be quite significant in an area having so scant a supply of energy resources and so substantial a requirement for energy.

West South Central

This region, composed of Arkansas, Louisiana, Oklahoma, and Texas, is in general relatively lacking in potential water power. The four States together include 14.5 percent of the land area and in 1930 had 9.9 percent of the population. They have only 1.8 percent of the water power and less than 1 percent of the waterwheel capacity. In 1937, these four States produced nearly 66 percent of the national output of oil and around 62 percent of the natural gas. Oklahoma, Arkansas, and Texas together produced also around 4 million tons of coal in 1936. Far the greater present dependence for energy, however, is on oil and gas, the present aspect of energy use in these States being tremendously affected by the vigorous exploitation of oil and gas resources.

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[67] Fritz and Veenstra, *op. cit.*, p. 87.

[68] National Resources Committee, *Drainage Basin Problems and Programs*, 1936 edition, pp. 59–60, and 1937 revision, pp. 31–33. For an excellent brief high-lighting of the "dust bowl," see Kimmel, Roy I., "A United Front to Reclaim the Dust Bowl," *New York Times Magazine*, August 14, 1938. Refer also to Lord, Russell, *To Hold this Soil*, U. S. Department of Agriculture, Miscellaneous Publication No. 321 (1938), pp. 63–80. See Webb, Walter Prescott, *The Great Plains*, Ginn and Company, 1931, especially ch. VIII, "The Search for Water in the Great Plains."

Arkansas is estimated to have feasible undeveloped water power enough for an annual production of nearly 2.3 billion kilowatt-hours. The estimated total output from water wheels in 1937 was 151 million. Even this relatively low degree of development produced 54.5 percent of the utility output of electricity in Arkansas. It should be observed, however, that Arkansas has high-capacity transmission ties to fuel plants in Tennessee and Louisiana. Arkansas produced 1.6 million tons of coal, 10.5 million barrels of oil, and 8.5 billion cubic feet of natural gas in 1936. Estimated bituminous coal reserves aggregate nearly 1.3 billion tons; and anthracite reserves total 223 million. If considered on a strictly power basis, water resources there might remain largely undeveloped, at least until after the exploitation of oil and gas in Arkansas, Louisiana, and east Texas had slowed down. But one may doubt that the increasing pressure of other water problems will permit ignoring the rivers. The Blakely Mountain project, authorized in 1938, represents a combination plan of public participation in private development for the purpose of attaining the combined objectives of flood control, navigation, and power production.

In Louisiana, oil production in 1937 amounted to 91,000,000 barrels; natural gas production, 315 billion cubic feet. Both oil and gas exploration and production expanded in 1937. No water wheels are reported for the State. The larger water problem consists in finding ways to get rid of water faster. The Federal Power Commission estimates feasible water power enough to produce more than 1 billion kilowatt-hours annually. Problems of flood control loom so large, however, as to necessitate their being emphasized in any water-control plan.[69]

Oklahoma is estimated to have feasible potential water power sufficient to produce close to 1.6 billion kilowatt-hours annually. Hydroelectric generators supplied a negligible proportion of her utility output of electricity in 1937. There was reported production of 229 million barrels of oil and 336 billion cubic feet of natural gas in 1937. When the supply of cheap oil and gas has become restricted, Oklahoma will still have large coal reserves, aggregating 54.8 billion tons, to draw upon. Although there may be eventual development of considerable water power, the problems of flood and drought are likely to be of primary significance in the development of water resources in that area. Plans for such development inevitably involve the interests of neighboring States.[70]

Estimated energy output of water wheels in Texas was about 110 million kilowatt-hours in 1937. Feasible output from undeveloped water power in the State is estimated at more than 1 billion kilowatt-hours annually. Electric utility plants there in 1937 used 635,000 tons of coal and lignite and 336,000 barrels of fuel oil; but their main fuel was 42.8 billion cubic feet of natural gas. There are some developments of water resources under way, mainly on the Colorado River, and others are discussed. But the aggregate expectation of water power is not large relative to the State's power requirements. Flood control is a problem in much of the State's area; and irrigation and storage of water for livestock are important problems in the middle and western part of Texas. The Texas Planning Board, although doubtful of the competitive feasibility of some of the power developments proposed in connection with the Colorado and Brazos projects, nevertheless points out the substantial possibilities in those projects of power for peak loads.[71]

Mountain Division

The Mountain division is far the largest of the census groupings of States, including nearly 29 percent of the national-land area. Of the estimated water power available 90 percent of the time, as estimated by the Geological Survey in 1936, the portion in the Mountain division amounted to 10,775,000 horsepower, or one-fourth of the national total. According to the recent estimates by the Power Commission, about 22 percent of the undeveloped water power of the country is located in that region. The area has only 3 percent of the population, however. Coal reserves in the Mountain division in 1928 were estimated at 353 billion tons of bituminous, 765 billion tons of subbituminous, and 315 billion tons of lignite. If all grades of black coal and brown coal are considered in terms of B. t. u., these reserves constitute about 42 percent of the national total. This group of States has perhaps 5 or 6 percent of the oil reserves and 2 or 3 percent of the gas reserves.

Almost the same in area as the whole territory east of the Mississippi, the Mountain division is somewhat below the national average in potential water power per square mile but much above the national average in coal reserves (considered on a B. t. u. basis). Both the coal and the potential water power are very unevenly distributed. Moreover, in far the larger part of that huge area a major fight is with desert or semidesert conditions, and a persistent water problem hinges about irrigation and the related requirement of power for pumping.

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[69] National Resources Committee, *Drainage Basin Problems and Programs* (1937 Revision), pp. 37, 69–75.

[70] *Ibid.*, pp. 33–35.

[71] Texas State Planning Board, *Markets for Texas Hydroelectric Power* (1937), pp. 2–5.

Industrial use of power in the Mountain division relates largely to the minerals industries. Far the larger part of our copper production is from States in this group. More than half of the lead output, close to one-third of the zinc, something like two-thirds of the silver, and close to half of the gold (exclusive of Alaska and the Philippines) also come from the Mountain division. New Mexico is one of the two principal States for potash. Phosphate-rock deposits of huge proportions are found in Idaho and lesser but important additional amounts in neighboring States.[72]

The basic necessity of phosphate in agriculture and the limited reserves in chief producing States (Florida and Tennessee) have already brought the problem of developing western deposits to the attention of the Congress.[73]

Copper production in the Mountain States is an industry of great magnitude. World production and market conditions are such as to cause great instability. Revival of the world copper market depends on revival of capital-goods industries. One need not discount too much the importance of cheap power in the West, but the hazard of great instability to workers and capital in the industry would hardly be removed by the temporary stimulus. Both recognition of possibly more limited outlook in capital-goods development and resort to international action seem to be required before any genuinely stabilizing result may be expected. Cheaper power, with inducement toward conservation, however, might aid in the development of lower-grade uses and reduce the threat to our limited deposits of high grade.[74]

Arizona was estimated by the Geological Survey in 1936 to have water power available 90 percent of the time in the amount of 3,710,000 horsepower. With 3.8 percent of the land area and only four-tenths of 1 percent of the population, the State had 8.7 percent of the comparable national total of potential water power. Allocation of potential water power in these estimates, of course, is in terms of the location of existing and probable power sites. Use of a very large block of power from the Colorado River is allocated to California. The growth in the use of water power in Arizona is reflected by the following totals of water-wheel capacity for specified years: 1921, 39,000; 1925, 49,000; 1927, 59,000; 1928, 104,000; 1930, 120,000; 1931, 137,000; 1937, 193,000. This development has been largely by public or cooperative agencies, about 95 percent of the hydroelectric generator capacity at the end of 1937 belonging to the United States Bureau of Reclamation, the United States Indian Irrigation Service, and the Salt River Valley Water Users Association. The relatively great importance of power for pumping water for irrigation is reflected in the agencies of development.

Water-driven generators constituted 56.3 percent of the utility generator capacity in Arizona at the end of 1937 and provided 58.7 percent of the output of electricity. Fuel plants used oil or gas, a total of more than one-half million barrels of fuel oil and 1.8 billion cubic feet of natural gas being used by Arizona utility plants in 1937. The capacity of generators in fuel plants was 98,487 kilowatts. Of this total, generators driven by internal combustion engines aggregated 25,835 kilowatts. When use of fuel oil in Diesel engines is allowed for, the comparatively large dependence of steam plants on natural gas is apparent. Moderate reserves of low-grade bituminous coal exist in the northeastern part of the State; but little production is reported.

Because of the developments on the Colorado River, the relative significance of water power among the sources of energy no doubt will be considerably increased within a few years. Although Arizona, in common with a number of the other western States, makes extensive use of power in the mining industry, it is expected that very substantial blocks of power from the Colorado River will be used in pumping for irrigation. Of the available prime power at Boulder, Arizona has an option on 18 percent, under existing allocations. Such allocation amounts initially to 765 million kilowatt-hours annually; the estimated energy output of all water wheels in Arizona in 1937 was around 422 million. Although prospective loads in most of Arizona may not be such as to justify very high voltage lines from Boulder Dam, it is probable that much power will be taken from there, largely for irrigation, but also for minerals industries. Substantial additional power is available in the Gila River Basin and in the Little Colorado.

Idaho is second among the Mountain States in the 1936 estimate of potential water power. Recent estimates of the Power Commission on feasible undeveloped power place Idaho far above the other States of that group. The change represents largely the effect of developing plans for the Snake River Basin. Estimated total production at hydroelectric plants in that State in 1937 was less than one billion kilowatt-hours. Estimated feasible output from undeveloped water power is 19.9 billion. Utility output there is practically 100 percent hydro, and only one-tenth of the hydro capacity in Idaho is Federal and municipal.

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[72] *Minerals Yearbook, 1938*, pp. 58, 85, 117, 141, 1172, 1240. The production record of the several important minerals over a long period is considered in National Resources Committee, *Mineral Reserves of the United States and Its Capacity for Production* (1936), a report prepared by Kenneth Leith and Donald M. Liddell for The Planning Committee for Mineral Policy.

[73] Seventy-sixth Cong., 1st sess., *Senate Document No. 21.*

[74] Cf. *National Resources Board, Report, December 31, 1934*, pp. 408–11.

Most of the present capacity of hydroelectric plants had been developed by 1928.

Idaho has relatively small coal reserves. The hydroelectric capacity, however, is sufficient to provide large amounts of surplus power for consumption outside the State, especially in Utah. The larger water-power plants, which are in the southeastern part of Idaho, are tied to the Salt Lake City area.[75]

The constitution of the State of Idaho provides that first claim on water in the State shall be given to irrigation; and there, as in other Western States, the requirement of water for agricultural purposes must be considered in determining the pattern of release of water for power production. The comprehensive plan being considered, especially for the Snake River and its tributaries, embrace provision for flood control, irrigation, and power production, the possibility of the latter being large in spite of the agricultural limitation. The Pacific Northwest Regional Planning Commission visualizes not only the high-voltage tie with the Salt Lake region of Utah but also a high-capacity tie westward with the Columbia Basin plants and northward to Great Falls.[76] Except for irrigation, largely in the Snake River Basin, and lumbering in the timbered northern section, the probable Idaho market seems to relate largely to the minerals industry. Special attention, as we have noted above, is being given to the development of phosphate, of which Idaho has large deposits. A line of 220,000-volt capacity from the Columbia project to reach the phosphate fields of southeastern Idaho was recommended by the late Administrator of the Bonneville project.[77]

Utah is estimated to have feasible undeveloped water power enough for an annual output of close to 8.3 billion kilowatt-hours. The estimated output of water-power plants in 1937 aggregated only 299 million kilowatt-hours, only a small part of the total waterwheel capacity being outside utility plants. About 58 percent of the production of electricity in Utah is from water power; but the very large importation of power from Idaho, where the production is almost totally hydro, means that Utah has a much higher ratio of dependence on water power than that indicated by production in the State.

Coal reserves in Utah aggregate 93 billion tons, mostly bituminous. Producing fields are near the middle of the State; additional reserves are in the southwestern quarter. Coal production in predepression years averaged between 4 and 5 million tons, falling considerably below 3 million in the depression years. About 42 percent of the utility production of electricity in the State is from fuel, largely coal. The power lines in the Salt Lake City area link fuel and hydro plants, including large hydro plants in southeastern Idaho.

The larger uses of power in Utah are in the minerals industry, which in very considerable part is concentrated in Salt Lake County and a few neighboring counties. Power possibilities in that portion of the State are partly in rivers emptying into Great Salt Lake, but mostly in the Green River. The Planning Board considers large-scale development on the Green River to be the most promising likelihood for the northeastern section of the State. The transmission distances and some of the development problems, however, are such that the Planning Board also has given serious consideration to production of power from coal.[78] The power possibilities on the Colorado River in Utah are in the southern part of the State, rather distant from that part of the State in which the more important loads are located.

Feasible undeveloped water power in Montana is estimated to be sufficient for an output of close to 10.3 billion kilowatt-hours annually. In 1937, total hydro output in the State approximated 1.3 billion kilowatt-hours. In considering the latitude for possible expansion of water power, it is necessary to keep in mind that Montana has substantial deposits of low-grade bituminous coal and huge amounts of lignite. At present, the electrical utilities make little use of the available fuel, 98 percent of the output of electricity in that State in 1937 being from hydroelectric generators. Practically all the use of water power is in privately owned utility plants. In other words, private business has preferred water power over fuel for the production of electricity in Montana.

In 1929 a total of 402,000 horsepower of prime movers and motors driven by purchased energy was reported for manufacturing and mining in Montana. Of this total, 347,000 horsepower was in the form of motors driven by purchased energy. Thus, the dependence of industry on electricity, and, therefore, on water power, is very marked. Further development for outright industrial reasons no doubt depends much on the turn of events in the copper industry. It seems likely, however, that the scarcity of water for agricultural purposes, coupled with the rather paradoxical plague of floods in a generally arid section, will lead to some development of the multiple-purpose type in Montana.

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[75] Federal Power Commission, *National Power Survey, Interim Report*, Power Series No. 1 (1935), map facing p. 6.

[76] National Resources Committee, *Regional Planning, Part I—Pacific Northwest*, map facing p. 40.

[77] U. S. Department of the Interior, *The Bonneville Project*, Bulletin No. 31, January 20, 1939.

[78] Utah State Planning Board, *Mineral Industries Survey* (1935) and *Preliminary Statement Concerning Possible Sources of Low-Cost Power for Salt Lake Region* (1935).

Perhaps the purposes of the Fort Peck project, now related mainly to navigation in the Missouri River, will need to be broadened in terms of requirements in areas closer to the project.

Colorado was estimated in 1936 to have potential water power amounting to 647,000 horsepower available 90 percent of the time. In terms of area, the estimate is far below the national average; the average per capita, however, is substantially above the national average. Regarding feasible development with regulation of stream flow, a major difficulty in Colorado is related to the finding of reservoir space in the steep, narrow canyons. Another limitation on power development rests in the necessity of using considerable portions of the available water for irrigation, that use necessarily governing the timing of much of the release of water where storage is developed. A further major difficulty lies in the fact that an important part of the water is separated by the mountains from the larger power load and irrigation needs. Plans for transmountain diversion have received earnest consideration, and one, the Colorado-Big Thompson diversion, is under way. Both important power output and a very significant lift for agriculture under irrigation are believed to be possible through such diversion.[79]

At the end of 1937 Colorado had 105,000 horsepower of water-wheel capacity. Far the larger share of this total appeared before 1921. About one-fourth of the generator capacity of utilities in Colorado at the end of 1937 was hydro.

Coal reserves in Colorado aggregate more than 300 billion tons, about two-thirds being bituminous and, roughly, one-third subbituminous. The State also has some anthracite deposits. Coal production there reached a maximum of 12,483,000 tons in 1917; in 1929 the total was below 10 million. Oil production is relatively small. For natural gas, the State has a trunk line reaching from the Texas Panhandle fields, and utility plants in Colorado consumed 476 million cubic feet of natural gas in 1937. Their main dependence, however, is still on coal.

Wyoming was estimated in 1936 to have potential water power of 571,000 horsepower available 90 percent of the time. The amount per square mile is comparatively low; in view of the sparse population, the per capita is comparatively high. Only a small portion of the available water power in Wyoming is in use, the aggregate capacity of installed water wheels at the end of 1937 being only 24,000 horsepower, nearly all in utility plants. Hydroelectric generators constituted 30 percent of the electric utility generator capacity. The reports for manufacturing and mining in 1929 showed only 98,000 horsepower, including about 41,000 horsepower of motors driven by purchased energy. The aggregate use of power, in other words, is at relatively low stage in Wyoming. In view of the floods and the aridity, power production will necessarily be largely controlled by the main considerations of flood control and irrigation.

At the end of 1937 approximately one-ninth of the fuel-driven generator capacity in Wyoming was powered by internal-combustion engines, which appear to be especially adaptable to small-plant use. In the steam plants, although there was substantial use of natural gas, the main dependence was on coal. In time, as rising price of fuel oil may necessitate, the State can turn more to the large subbituminous coal deposits. But it must be noted that, even for that recourse, limited availability of condensing water will constitute a hurdle.

Nevada's share of feasible undeveloped water power is estimated to be enough to generate 2.6 billion kilowatt-hours annually. Output of water wheels in 1937 is estimated at 1.1 billion. A large part of the production at Boulder Dam will be used by southern California. Nevada's prospective use of power is relatively minor in comparison with its nominal quota of potential power or of production. Like Arizona, Nevada has an option on 18 percent of the firm power at Boulder. The allocation, aggregating 765 million kilowatts, is four and one-half times the amount of electrical energy used in the State in 1935. The larger hope for use of that vastly increased power is in minerals industries.[80] Most of the State lies in the Great Basin, which is notably arid. In the main, the streams in the Great Basin are rather fully appropriated. Provision of numerous reservoirs for stock watering has been proposed for the huge area fit only for limited grazing. In parts of the Great Basin surface water is too scarce even for that, although to some extent an alternative exists in drilling for ground water.[81]

New Mexico has very little water power and only minor hydroelectric development. Some possibilities on the upper Rio Grande are indicated, under the pending agreement with Texas and Colorado on development and division of the water resources. But the agreement, related to scarce water, probably will concern in considerable part agriculature, rather than industrial power. Adequacy of power for potash production, however, is of sufficient special national importance to warrant close attention to water power resources of New Mexico.

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[79] Colorado State Planning Commission, *Development of Electric Power Industry in Colorado* (1938), Foreword and pp. 138-39.

[80] Nevada State Planning Board, *Electric Power in Nevada* (1937), pp. 88, 91.

[81] National Resources Committee, *Drainage Basin Problems and Programs* (1937 revision), pp. 43–45.

Pacific Division

The three States, Washington, Oregon, and California, according to the 1936 estimates, had over 41 percent of the country's water power, although they have together less than 7 percent of the population and only 10.7 percent of the land area. The aggregate of estimated potential water power in this group in 1936 was 17,734,000 horsepower available 90 percent of the time. The average water power per square mile is only a little short of four times the national average; the average per capita, in terms of 1930 population, is more than six times the national per capita. In approximate proportions, one-half of the total is in Washington and one-fourth in each of the other two States.

The relatively advanced use of water power in the Pacific division is clear from the fact that, with only 10.7 percent of the land area, that section had 23.5 percent of total national capacity of installed water wheels and 25.5 percent of hydroelectric generator capacity at the end of 1937. The estimated total output of all water wheels in the three States was around 12.9 billion kilowatt-hours in 1937. Feasible undeveloped power is estimated by the Power Commission to be sufficient for an additional annual output of over 142 billion.

The known fuel reserves in the Pacific States consist mainly of oil and gas in California and coal in Washington. Coal beds in Washington are estimated by the Geological Survey to approximate 11.3 billion tons of bituminous coal and 52.4 billion tons of subbituminous, with relatively small amounts of other grades. California oil reserves are estimated at about 3 billion barrels. Electric utility plants in Washington used 17,500 tons of coal in 1937; no coal consumption was reported by plants in Oregon and California. The utility plants in the three States together burned 1,932,000 barrels of fuel oil in 1937, the rough equivalent of 483,000 tons of bituminous coal. Although neither Washington nor Oregon produces a significant amount of oil, Washington plants burned 641,000 barrels and Oregon plants burned 542,000 barrels. California plants, in addition to using 748,000 barrels of fuel oil, burned nearly 15.6 billion cubic feet of natural gas. It is true that only about 14 percent of the electricity produced in the Pacific division was from fuel plants; but for that fraction the present dependence is on a vulnerable fuel supply.

In Washington and Oregon use of wood waste as fuel is of some importance. Of 465 million kilowatt-hours reported in the country as generated from wood in 1937, these two States reported approximately 411 million, which is nearly half of the fuel-generated power reported by their utility group.[82] Very extensive use of wood waste from sawmilling and woodworking in Washington is noted by the Washington State Planning Council. The use extends, of course, to steam raising for industrial purposes and to heating homes. Even if water storage and interconnection of hydro plants should eliminate the need for stand-by steam plants in the utility industry, extensive use of wood waste for private industrial plants is expected to continue until higher uses are found for such waste.[83] In 1934, more than 72 percent of the dwelling units in the metropolitan district of Portland and 34 percent of those in the metropolitan district of Seattle were reported to be heated with wood.[84] Although continued use of large quantities of wood for fuel may be expected, the high prices of lumber and other wood products, the increasing tendency to retrieve and process wood waste, and the comparative exhaustion of important forest areas by cutting, fires, and tree disease [85] will tend to restrict use of wood as fuel.

With the abundant hydroelectric power being made available in new developments of the Pacific Northwest, it is not probable that the eventual diminution of the oil supply from California would soon cause any great increase in the use of the relatively high-cost Washington coal for power, although it may be required for heating purposes. And coal that is probably of too high a relative cost to be used in great amount for power at or near the coal beds is unlikely to flow heavily into Oregon and California for power production, although it may be needed there for heating purposes.

Potential water power in Washington was estimated in 1936 at 8,768,000 horsepower available 90 percent of the time. Total output of all water wheels there in 1937 is estimated at nearly 3.4 billion kilowatt-hours. Feasible undeveloped power is estimated by the Power Commission to be great enough for an output of 72.7 billion. In the introductory section of this chapter, it was pointed out that there are numerous uncertain factors in the estimates of available water power. Such uncertainties are recognized by those close to the problem of the Pacific Northwest.[86] There is, however, no room for disputing the existence of huge undeveloped water power in Washington.

Mean rainfall is very heavy in the western part of Washington but very light east of the Cascades. The precipitation in the western part of the State is especially heavy during the winter months, when the moist, prevailing westerly winds strike the cooler mountain sides. The summer rainfall is generally light. East of the Cascades, there is comparatively light rainfall even in the winter, the winds commonly having dropped most of their moisture before crossing the divide.[87]

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[82] Federal Power Commission, *Electric Power Statistics, 1937*, p. 11.

[83] Washington State Planning Council, *Energy Resources, State of Washington* (manuscript of P. Hetherton, August 1938, with revisions October 1938), pp. 1, 5–6.

[84] U. S. Department of Commerce, Bureau of Foreign and Domestic Commerce, *Real Property Inventory, 1934—Summary and Sixty-Four Cities Combined*, pp. 27, 29.

[85] On forest resources and depletion, refer to National Resources Committee, *Forest Resources of the Pacific Northwest* (1938), especially pp. 10–14.

[86] Washington State Planning Council, *op. cit.*, p. 3.

Although all of the rivers of Washington empty eventually into the Pacific Ocean, it is well to distinguish three major drainage systems—the Pacific coast belt, the Puget Sound Basin, and the Columbia River system. The coast belt is relatively narrow but has the heaviest mean rainfall. It is cut by a number of relatively short rivers which, in the winter months, spill into the Pacific the enormous runoff of the western slope. Significant power sites are indicated for the coastal belt, although development thus far has been limited in that area. The greater developments of the State, until very recent years, were in the Puget Sound Basin. The relatively great concentration of water power in the western part of the State may be noted from the fact that, in the Pacific Northwest, the coastal drainage areas, exclusive of the Columbia, covering only about one-seventh of the area, have practically half of the mean annual runoff.[88] In short, although the power drama of Washington currently attaches to the large developments on the Columbia River, the previous development had been largely in the Puget Sound Basin, and there remains much undeveloped power in the coast belt and in the Puget Sound area.

At the end of 1937 hydroelectric generators constituted nearly 79 percent of the utility generator capacity in Washington; over 88 percent of the 1937 output of utility generators was hydro. None of the new Federal capacity is included in these 1937 figures (only the relatively minor Federal capacity of national parks and reclamation being included). On the other hand, public development there did not begin with the Federal works. The Census of 1932 showed close to one-third of the generator capacity to be in municipal plants. Municipal plants, mainly in Seattle and Tacoma, had about 43 percent of the capacity in August 1938.[89]

Designs allow for an ultimate generator capacity of 504,000 kilowatts at Bonneville, its availability divided between Oregon and Washington. In July 1938 installed capacity was 86,400 kilowatts. At Coulee the ultimate capacity is stated at 1,890,000 kilowatts. The first unit is expected to go into operation early in 1942.

So great a prospective increase of power raises obvious questions of markets. Increased domestic and farm use, increased use by existing industries and transportation, uses for irrigation, and new electrochemical and electrothermal industries are considered in the possibilities of expanding use.[90] The importance of irrigation alone is great at Coulee.[91] The immense importance of lumbering and the related need for conservation and reforestation have been emphasized.[92] Attention has been called to the possibly severe unbalancing effect that might come with the establishment there of great power-consuming heavy industries.[93]

But at any rate, abundant power is in sight; cheap power is the goal; and rates announced for Bonneville represent a confident attempt to see what cheap power will do. The announced rates are as follows:

SUMMARY OF WHOLESALE RATES

Primary Power (on Bonneville Transmission System), at $17.50 kilowatt-year.
Secondary Power (on Bonneville Transmission System), at $11.50 kilowatt-year.
Primary Power (at the Bonneville Power Plant), at $14.50 kilowatt-year.
Secondary Power (at the Bonneville Power Plant), at $9.50 kilowatt-year.
Special Developmental Rate for cooperative associations and other small users for primary power on the system, at ½ cent kilowatt-hour.

Half of the power of Bonneville is being reserved for public power districts, cities, and cooperative associations. Although the rates these districts will charge are not fixed, the late Administrator published what he visualized as an "objective" rate schedule, as "a mark for public bodies to shoot at." He proposed a minimum domestic bill of 50 cents and bracket rates as follows, on monthly bills:[94]

First 50 kilowatt-hours, at 2½ cents per kilowatt-hour.
Next 100 kilowatt-hours, at 2 cents per kilowatt-hour.
Next 100 kilowatt-hours, at 1 cent per kilowatt-hour.
Next 1,700 kilowatt-hours, at ½ cent per kilowatt-hour.

In Oregon, which is considerably larger than Washington, potential water power is roughly half that of

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[87] Professor Carl Edward Magnusson, University of Washington, has made illuminating reports on the topography, precipitation, and drainage in Washington. Refer especially to *University of Washington Engineering Experiment Station Series, Bulletin No. 26* (1924); see also *Bulletin No. 78* (1935) and *Bulletin No. 90* (1936). In view of the overlap of important drainage basins into Canada, Professor Magnusson has considered the international boundary waters in *Bulletin No. 96* (1938).

[88] National Resources Committee, *Regional Planning, Part I—Pacific Northwest* (May 1936), p. 35.

[89] Data from the Federal Power Commission.

[90] Washington State Planning Council, *op. cit.*, pp. 16–25. National Resources Committee, *Regional Planning, Part I—Pacific Northwest* (1936), pp. 91–94

[91] Sperrett, R. G., "Grand Coulee Progresses," *Scientific American*, December 1938. U. S. Department of the Interior, Bureau of Reclamation, *General Information Concerning the Columbia Basin Project* (release of March 1, 1938), p. 4.

[92] National Resources Committee, *Forest Resources of the Northwest* (1938).

[93] Wheeler, Bayard O., *Journal of Land and Public Utility Economics*, vol. XIV, No. 4 (November 1938), pp. 367–368.

[94] U. S. Department of the Interior, *The Bonneville Project*, Bulletin No. 19, June 13, 1938, and press release N–126, October 25, 1938.

Washington. The 1936 estimate for Oregon was 4,361,000 horsepower available 90 percent of the time and 5,956,000 available 50 percent of the time. Estimated energy output of water-power plants there in 1937 was somewhat over 1.1 billion kilowatt-hours. Feasible undeveloped power is estimated to be great enough for an output of nearly 34.5 billion.

At the east, Oregon shares with Idaho the power possibilities of the Snake River. At the north, the Columbia is a common boundary with Washington along about three-fourths of the Oregon line, and Oregon is to be reached by the network of the Columbia projects. The western band, somewhat like that of Washington, has short rivers. The south central section of the State, however, lies in the arid Great Basin.

At the end of 1937, the capacity of installed water wheels in Oregon was 367,000 horsepower; of this capacity, 83.5 percent was in utility plants. No Federal capacity is included, and municipal plants account for only about 6 percent of the hydro power. In other words, Oregon water-power development has been predominantly private. At the end of 1937, hydro capacity constituted 49.5 percent of the capacity of utility generators; in 1937, hydro output constituted 72.4 percent of utility output. Furthermore, more than one-fifth of the capacity of prime movers reported for 1929 in manufacturing and mining plants in Oregon was made up of water wheels.

Known fuel deposits in Oregon consist of only limited coal, largely low grade, in the northwestern part. Coal production reported is negligible. Utility power plants burning fuel reported no use of coal or gas. Of 384 million kilowatt-hours produced in 1937 by fuel plants, 208 million came from use of wood fuel, the remainder being from fuel oil.[95] With the allocation of large blocks of cheap power from the Columbia (refer to Bonneville rates above), and with the general national tendency toward higher uses of wood, the tendency in Oregon probably will be toward less rather than more use of fuel in power plants. The broad considerations mentioned above with reference to the problem of markets in Washington apply in general to Oregon also and need not be repeated. Relevant to that problem, we may observe that the city of Eugene, 160 miles from Bonneville, has announced the following residential schedule:

First 15 kilowatt-hours at 4 cents per kilowatt-hour.
Next 25 kilowatt-hours at 2 cents per kilowatt-hour.
Next 60 kilowatt-hours at 1.7 cents per kilowatt-hour.
All over 100 kilowatt-hours at 1.2 cents per kilowatt-hour.
Minimum charge, 60 cents a month.

A high-voltage transmission line is being constructed southward from Bonneville, to reach Eugene by the fall of this year; and the expected increase of consumption of electricity at Eugene is to be met from Bonneville.[96]

Bulk use of power in Oregon, however, depends on industrial outlet. Overwhelmingly the larger part of Oregon's employment is in agriculture and production of timber and wood products. Lumber production, developing very rapidly up to 1929, has, of course, felt the sustained restriction nationally in building activity, an important part of the market being east of the Mississippi (reached through the Panama Canal). Growing importance has attached to paper pulp production, and the rayon industry is considered a possibility. There is some expectation of growth also in plywood and furniture manufacture. And other manufacturing industries, individually of relatively small proportions, offer combined possibilities of some importance. In agriculture irrigation is resorted to in a number of the valleys. Recent developments of irrigation in the Willamette Valley have yielded surprising results. Reclamation developments in eastern Oregon are adding considerable acreage suitable for fruits and vegetables.[97]

California has, according to 1936 estimates, total potential water power in California is much lower per Oregon and roughly half that in Washington. The State is much larger and much more populous than either of the other Pacific States. Consequently, the potential water power in California is much lower per capita and per square mile than that in the other two States of the west coast. On the other hand, the water-wheel capacity in California constitutes about 60 percent of that in the Pacific group.

With 4.6 percent of the national population and 5.2 percent of the land area, California has 10.8 percent of the water power, 14.1 percent of the water-wheel capacity, and 16.2 percent of the utility hydro capacity. The estimated total output of energy from water wheels in 1937 was around 8.4 billion kilowatt-hours, almost equal to that of the South Atlantic division and about one-fourth larger than that of the State of New York. The relatively high use of water power, however, does not mean lack of latitude for further hydro development. Feasible undelevoped water power in the State is estimated to be sufficient for generation of close to 35 billion kilowatt-hours.

California utility plants using fuel burned approximately 753,000 barrels of fuel oil and 16.2 billion cubic feet of gas. The State has very minor coal reserves and negligible coal production and reported no use of coal in utility power plants in 1937.

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[95] Federal Power Commission, *Electric Power Statistics, 1937*, pp. 11–13, 19–24.

[96] U. S. Department of the Interior, *The Bonneville Project*, Bulletin No. 32, February 1, 1939.

[97] Abstracted from Oregon State Planning Board, *Location and Growth of Oregon's Basic Manufacturing Industries* (1938).

In California large power possibilities are combined in rather uncertain proportions with problems of flood control, irrigation, and public water supply. California is a major agricultural State, in spite of limited rainfall. Irrigation is a necessity to the agricultural industry. Meanwhile, great metropolitan areas on the coast have outgrown their water supply. The compounding of these water problems makes development of water resources a necessity, and considerable joint product or byproduct power is a likely prospect.

Of the prime power output at Boulder, 28 percent, or approximately 1.3 billion kilowatt-hours annually, has been allocated to the cities and major utility companies of Southern California. In addition, 36 percent, close to 1.6 billion kilowatt-hours, will be taken by the Metropolitan Water District (Los Angeles and neighboring cities) for pumping water from the Colorado. Meanwhile, however, surveys of the State's own water resources have proceeded, with close regard for the necessities of agriculture and public water supply.[98] A large development now in process is that of Shasta Dam in the Sacramento River, 14 miles north of Redding. Designs provide for 350,000 kilowatts of generator capacity.

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[98] California State Planning Board, *Present and Potential Power Development, California* (Manuscript, 1936).

CHAPTER 4.—INTERCONNECTION OF ELECTRIC POWER PLANTS IN RELATION TO DEVELOPMENT OF WATER POWER

At various points in preceding pages, mention has been made of interconnection among generating stations. Although it has been shown that water power is far too limited to meet our energy requirements, we find water power used at least somewhat in most of the States; and we find it the main source of power in some States. Furthermore, we observe that interconnection of hydro plants with fuel plants is quite prevalent. It is in point to consider briefly the reasons for interconnection and the special place of hydro in interconnected systems.

General Reasons for Interconnection

The broad reasons for interconnection are reduction of cost and increase of reliability. Reduction of cost through interconnection relates largely to greater diversification of load, reduction of the proportion of capacity necessary for reserve, use of the more efficient capacity for a greater part of the total output, and closer adjustment of increase in capacity to increase in requirements.

Diversification of Load

Demand for electricity fluctuates widely. To assure service, a system must have, or must be able to draw on, capacity great enough for the largest probable peak load, plus reserve against breakdown. Within the business cycle, depression levels of industrial activity one-fourth or more below peak levels are common. Within the year, because of seasonal fluctuations and other instabilities, the output of the low month may be 10, 20, or 30 percent below that in the high month,[99] and monthly totals do not show the full range of seasonal fluctuation. Typical daily fluctuations in load may require at the peak a supply of energy three, four, or more times that of typical low level of requirements.[1]

In 1937 the average output of electrical energy was approximately 3,300 kilowatt-hours per kilowatt of capacity reported.[2] Thus, the average capacity-use factor for the year was below 38 percent. This percentage, reflecting great excess of capacity over average use, is, in fact, a comparatively high percentage; earlier percentages reflecting annual average proportions of capacity in use were typically lower.[3]

It must be clearly understood that a relatively low capacity-use factor does not mean that capacity is greater than the load requires. It means merely that a large portion of the capacity, even if fully required for the peak, is idle most of the time. The hope of remedy lies in reducing the irregularity of the total load.

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[99] Monthly production totals for hydro plants, fuel plants, and all plants combined, as well as monthly sales totals for different classes of customers are shown for the years 1933–37 in Edison Electric Institute, *Statistical Bulletin No. 5* (April 1938), pp. 24–25. Monthly production totals by state and region for hydro plants, fuel plants, and all plants combined in 1937 are given in Federal Power Commission, *Electric Power Statistics, 1937,* pp. 6–13. Typical seasonal loads of New England districts in 1919 are charted in Murray, W. S., and Others, *op. cit.*, pp. 35–41.

[1] On daily loads, see Gibson, Norman R., "Rational Distribution of Electric Energy," *Third World Power Conference* (1936), sec. VI, Paper No. 16, p. 20. (Conference proof.) Daily load curves of (*a*) Pennsylvania Power and Light Company, (*b*) Philadelphia Electric Company and Public Service Electric and Gas Company, combined and (c) these three companies combined are given in Funk, Nevin E., "The Economic Value of Major System Interconnections," *Journal of The Franklin Institute,* August 1931. Reproduced in Securities and Exchange Commission, *Compilation of Information on Interconnection of Electric Utilities* (1936), following p. 11. For a highly illuminating summary of the significance of interconnection refer to Joel D. Justin, American Society of Civil Engineers, *Proceedings*, December 1937, pp. 1915–22.

[2] Total net output for the year divided by the average of capacity reported for December 31, 1936, and capacity reported for December 31, 1937. Federal Power Commission, *op. cit.*, pp. 2–3.

[3] Nourse, Edwin G., and Associates, *America's Capacity to Produce* (The Brookings Institution, 1934), pp. 476–77.

Most communities have wide variations in their demand for electricity, but communities may differ from each other a great deal with respect to the timing and the extent of their variations. Of especial importance is the fact that they differ with respect to the time of peak demand. This difference in time of peak demand appears not only with reference to variation of demand within the day but also with reference to differences among the days of the week and among months or seasons of the year.

As demand patterns of different sorts are put together, some of the high points of one fall at the time of lower points of others, with the result that variation in total demand is reduced. For any central station, a better sustained service demand is more likely if a variety of industries, commercial establishments, transportation requirements, and homes are being supplied than if operations are tied to the needs of only a few types of demand. And a still better reduction of variation may be found when the demands of several communities are served by one interconnected system.

Closing part of the spread between average capacity in use and capacity required for peak, i. e., improvement of load factor, means ordinarily reduction of cost per kilowatt-hour. This reduction in cost is obvious regarding interest, depreciation, and certain maintenance costs that must be incurred even for idle plants. But, for steam plants, the reduction of load variation also has an important bearing on operating cost per unit of output. Steam must be kept up sufficiently above immediate use to permit the prompt pickup of more load; and since the high-speed turbines of the steam station cannot be thrown into service when cold, a "hot reserve" of operating capacity is required, sufficient to assure sustained service against outage of the largest unit on the line.

Reduction in the Proportion of Reserve Capacity

To assure continuity of service, total capacity must exceed the capacity required on the line at the time of peak load sufficiently to carry on if the largest unit in service goes out. Meanwhile, because of economies of comparatively large generator units, the reserve unit or units in a small system constitute a significant proportion of capacity. But the likelihood of an outage in two or three neighboring systems at the same time is rather remote. Consequently, with interconnection, it is often possible to reduce the proportion of reserve capacity lower than in the isolated system. Such reduction brings about a reduction in overhead cost per unit of output.

Additions to Capacity

Total power requirements were growing fast before the depression. Growth of central electric station capacity was faster than the total growth, for the reason that an increasing portion of power machinery was being operated with electricity from central stations. Further growth is assumed. Although the economic size of additional units varies in different areas, advantages of fairly large units are such that increase of capacity for future demand may, in a smaller system, account for a significant percentage of the excess of total capacity over average use. In the larger area served by interconnected systems, the installation of the larger economic units is possible without the effect such units have in the more restricted system on the amount of idle capacity and, therefore, on the relative weight of fixed charges. Hence, there is better opportunity for gradual increase of capacity in accordance with increase in demand.

Use of the More Efficient Units

Different plants and different units therein are likely to represent a range of substantial difference in efficiency. There are obvious motives for carrying the larger part of the load with the more efficient equipment, placing the less efficient units in service only as necessary for peak service. Interconnected systems have better opportunity to maximize the use of the more efficient units and to minimize the use of the less efficient.

Water Power and Interconnection

Possible advantages of water power in the interconnected system relate to both overhead cost and operating cost.

If thought of with reference to capacity for fairly continuous operation, the cost per kilowatt in a steam plant typically is very much less than the cost per kilowatt in the hydro plant. Moreover, for large portions of the country, irregularity of stream flow and the limit in the amount of water power available even with storage render it necessary to provide fuel plants with capacity large enough for base loads. Granted that different cost relations hold with reference to the Niagara and the St. Lawrence, because of their great natural firm power, than with reference to the superstorage projects on the Tennessee, the Colorado, and the Columbia; granted also that further development of basin plans may materially alter cost relationships elsewhere; nevertheless, for most of the country at present, the high basic cost of hydro plants holds true.

With reference to incremental cost per kilowatt for reserve, however, something different is encountered. For steam-driven reserve, the necessary appurtenances—furnace, boilers, pumping equipment, etc.—must be in general proportion with generator capacity, even though it will be in use only a small part of the time. Consequently, the incremental cost for steam-driven reserve is not likely to be a great deal less than the basic cost of steam-driven capacity.

Ordinarily, to use water power at all requires the building of a dam, and at least some land for a pond is necessary. If generator capacity is installed merely in accordance with firm power available without storage, the cost per kilowatt of capacity is likely to be very high. And since, for much of the country, fuel-driven capacity would still be necessary, such hydro installation would be unlikely. But designed for peak use, a hydro plant with a moderate storage reservoir can carry for a few hours each day a load several times as great as it could carry continuously. Capacity far above firm power limits, aimed for peak purposes, can be provided in such a plant at a very low incremental cost per kilowatt.

Operating and maintenance cost of the steam-electric plant are generally recognized to be relatively high. Fuel cost is a large item; and a moderate fraction of the energy from the fuel is used in the operation of the plant itself, chiefly for firing and for pumping. Firing must go on for some time in advance of the rise in load, and there is inevitable loss of energy after the load goes down. Steam must be kept sufficient for a likely pick-up of load; and, since an idle steam turbine-generator unit cannot be thrown into service at once, it is necessary to keep a hot reserve in operation. Substantial maintenance cost is incurred because of numerous moving parts of firing and pumping machinery, great furnace and boiler heat, great boiler pressure, great heat on the turbine, and high speed of the turbo-generator unit.

An idle hydroelectric unit can be put into service almost instantly—sometimes automatically and often semiautomatically—and can be taken out of service with equal promptness when it is no longer needed. Therefore, a steam system with hydro reserve does not have to keep a hot reserve in operation. When stream flow materially exceeds that required for peak operations, some of the hydro capacity can be operated longer hours—further down the load curve—thereby reducing total operating cost. When, seasonally or in depression, the total load drops, operating costs may be trimmed substantially through maximum use of the hydro capacity.

Most of our streams have rather wide variation in flow. The pattern of variation differs considerably from stream to stream. Wide interconnection, therefore, affords opportunity to include stream diversity and thereby to provide a more dependable hydro reserve for the system.

Status of Interconnection

Electric light and power service was at first a distinctly local affair. With developing transmission methods and growth of local communities, larger and larger areas were served by individual central stations. With the expansion of service areas in the denser sections, the neighboring systems often came to constitute almost continuous series of systems. Numerous factors tended to encourage interconnection—such factors as improvement of transmission, development of interlocking financial interest, occasional emergencies, search for diversity of load, regard for the economy of larger generating units, the general overhead problem of reserve capacity, and recognition of the flexibility of water power and its especial advantages for peak. And in terms of closely neighboring areas, interconnection advanced a great deal. But it did not for a long time develop reach of either much capacity or much distance.

During the World War, power shortage was experienced in important centers, because of heightened industrial demand; shortages of fuel, caused by congestion of transport; shortages of water power, caused by extreme cold in the winter of 1917–18 and drouth in the summer of 1918; and curtailment of power from Canada, because of the rise of Canadian requirements. At the same time, there was surplus power available in some areas, and partial remedy was provided by interconnection.[4] But Secretary Lane said later that had hostilities continued we should certainly have faced an extreme power shortage.[5] The Geological Survey intensified its studies of the local and national power situation; and a special study was made of the great industrial seaboard area from Boston to Washington. The unnecessary waste incident to the production of power by unassociated units and the need for coordination of power production in that area were given forthright expression in 1921.[6] Industrial interests of New England were concerned about their power problem and asked for engineering consideration of it. Among the several cogent aspects of the resulting report was definite reference to the advantage of improved interconnection.[7] In 1923, Secretary Hoover conferred informally with the chairmen of the utilities commissions of the 11 northeastern States regarding possible State and Federal cooperation toward power development. There was then formed the Northeastern Super

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[4] Federal Power Commission, *National Power Survey, Interim Report*, Power Series No. 1 (1935), pp. 49–50.

[5] Quoted in Foreword of Murray, W. S., and Others, *A Superpower System for the Region between Boston and Washington*, U. S. Department of the Interior, Geological Survey, Professional Paper 123 (1921).

[6] *Ibid.*, p. 11.

[7] Main, Charles T., Harriman, Henry I., and Jackson, Dugal C., "Power Requirements and Sources of Supply of New England," *Journal of the Boston Society of Civil Engineers*, Vol. XI, No. 5 (May 1924), pp. 193–227, especially pp. 206–207.

Power Committee, composed of representatives of the several States and members from the Geological Survey, the Federal Power Commission, and the Army. The report of that committee stated, among other things, that about 45 percent of the companies were technically interconnected but that only about 8 percent of the interconnections had capacity large enough for effective interchange of power; and the need of additional interconnection was emphasized.[8]

In 1935 the Federal Power Commission pointed out that interconnection was relatively far advanced in portions of New England, the Pennsylvania-New Jersey area, the South Atlantic region, the Pittsburgh-Ohio industrial area, the Chicago district, and the States of Washington and California. But the Commission also said "it would appear that in none of these regions are all of the benefits possible from a high degree of interconnection and coordination being secured." A relatively high stage of development in the transmission network was especially observable in areas making significant use of water power. Considered broadly, a map of the main transmission network, as it stood in 1935, showed that in most of what appeared to be large regional continuities of ties there were links of low capacity, i. e., ties inadequate for large interchange of power.[9] Another map from the same survey showed clearly the patchwork of competitive system areas, differentiated according to holding-company controls or affiliations.[10]

From the National Power Survey of 1935 it was concluded that with return to prosperity levels many parts of the country would face power deficiency, although for other sections, fewer in number, surplus power seemed likely. In view of both the problem of ordinary economic requirements and the great significance of adequate power in national defense, recommendations were made both for the modernization and enlargement of capacity and for making the most of existing capacity by improved interconnection.[11] During floods of recent years numerous communities found that, with their own plants closed by high water, they had only lines of small capacity or no lines at all over which power available in neighboring communities might be transmitted. And on September 11, 1938, the *New York Times* reported that the War Department had called attention to the problem of eliminating "bottlenecks" in the transmission of electric power.

Public Interest in Interconnection

That the developing American interest in better interconnection of power facilities is in no sense a mere phase of the post-1929 economic struggle is obvious from the active concern manifest in the immediate postwar years. That it is in no sense a merely American interest is clear from the record of European experience spread through numerous reports presented at the Third World Power Conference held in Washington in 1936.

Assurance of Continuous Service

Perhaps the most widely recognized point of public interest in interconnection lies in the need of assurance against the severe consequences of a prolonged interruption in the supply of electricity. Urban communities are hardly conscious of how essential electricity is to them until the supply is interrupted. Such interruption does not mean merely lack of light, refrigeration, and radio in the home. It means also that most economic activity is brought to a standstill for lack of light and power. And it may mean danger of fire or epidemic because of its stoppage of the water pumps.

Continuity of transportation service has long been a recognized matter of public concern, and no prolonged interruption of train service is tolerated. Since electric power cannot be economically stored in quantity, complete continuity of electric service is perhaps more important to the public than assurance against temporary interruption in the movement of commodities. Furthermore, it may well be kept in mind that sustained transportation is in many places dependent to a great extent on sustained electric service.

Such continuity, of crucial importance to peace-time work and comfort, and an obvious requirement of national defense, does not mean merely the sustained flow of some electrical energy. It means adequacy of total energy available and the means to send it where it is needed. Thus, assuming enough generator capacity within transmission reach of the point of need, assurance of service requires transmission ties of substantial capacity to several possible sources.[12]

Reduction in Cost of Service

A second point of public interest rests on the possibility of reduction in cost that may be effected through interconnection. The electric utility industry, as a regulated industry, is also a protected industry. Protection of "natural" monopoly can deserve popular respect only as it is conducive to service that is better and cheaper than that obtainable under other conditions. Surely no arrangement that ought to survive can be aimed to prevent community realization of savings and service advantages made possible by advancing technology.

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[8] Northeastern Super Power Committee, *Super Power Studies for the Northeast Section of the United States* (1924), pp. 6–8.

[9] *Op. cit.*, pp. 7, 54, and map facing p. 6.

[10] Federal Power Commission, *National Power Survey, Principal Electric Utility Systems in the United States*, Power Series No. 2 (1935), map inside back cover.

[11] Federal Power Commission, *National Power Survey, Interim Report*, Power Series No. 1 (1935), pp. X–XI and 11–30, 49–50.

[12] Increased assurance arising from interconnection with hydro relates to both the comparatively greater freedom of hydro from breakdown because of greater simplicity, and the speed with which hydroelectric generators can be put into operation. Creager, William P., and Justin, Joel D., *Hydro-Electric Handbook* (John Wiley and Sons, Inc., 1927), p. 874.

It must be recognized, of course, that if all savings attainable through better integration of electric service had to be passed on to the consumer, there would remain no profit motive for bringing about such integration. Moreover, it is altogether likely that some developments of transmission networks, which may conclusively seem advisable in terms of the general welfare or in terms of specific considerations of national security, may not appear feasible in terms of the profit calculations necessary in private business. But these are only qualifications to be thought of as safeguards against blunders of policy. They do not alter the basic fact that improved interconnection may often subserve the public interest in cheaper electricity.

Relief From Urban Congestion

Another aspect of the public interest relates to the relief which the better development of transmission networks might be expected to provide from urban congestion and certain of the attendant social problems. Sheer physical complexity and unwieldiness of the congested center are seen in crowded streets and walks; the jam of crowded elevators, trolley cars, and busses; the maze of wires, cables, and pipes. Lack of healthful elbow room for light, air, and play space is glaringly typical. What is still more important, in terms of the large problem of individual and social security, is that in such urban congestion the worker is wholly removed from the soil as a source of even partial livelihood and, in general, is wholly dependent on tragically unstable commercial or industrial employment.

Direct use of steam for mechanical power has tended to concentrate population. With industrialization, we have more and more worked with power machinery. If power was a major item of cost, such machinery had to be placed where steam could be generated cheaply. That advantage depended on accessibility to cheap fuel and abundant water. The abundance of suitable water at mine-mouth was not common. Cheap power, therefore, came to be associated with favored spots which had abundant water, in river, lake, or bay, and comparatively cheap transportation of fuel. Although items other than power cost are important in location of industry, choice of industrial location was in large part confined to spots relatively favored for generation of cheap power. In an earlier day, choice was confined to spots having usable waterfalls or rapids.

Now, the central electric station still must be located at spots affording the opportunity for cheap steam and abundant condensing water or at spots having available cheap potential water power. But the machines driven by power from these central stations do not have to be so located. So far as the power requirement is concerned, their location merely has to be within economic reach of transmission from the central stations.

Some industries with large requirements for heat and water need locations similar to those favored for steam-electric stations, but rarely are their nonpower requirements for water in the almost astronomical proportions characterizing the water requirement of the steam-electric station. Some industries in which mass handling and closely knit successive steps are essential to economic production will continue to require large plants, but the economy of large size of plant does not connote any necessary economy of having large plants "all in a row." Some industries have an especially large problem of bulk transportation; but to this fact must be opposed the other fact that urban congestion is pressing upon us, among other problems, that of unscrambling a number of our transportation termini.

Granted the various qualifications, it remains hardly open to doubt that improved and extended transmission networks offer the possibility of substantial relief from urban congestion.[13]

Conservation

A fourth important point of public interest in more adequately interconnected power networks relates to the specific problem of conserving scarce fuels and to the more complex set of conservation problems involved in control and development of streams. That development of water power would make it easier to establish a more frugal use of oil, gas, and relatively scarce grades of coal is obvious enough. Meanwhile, the several aspects of stream control and development quite commonly require dams and reservoirs. Proper regard for the possibilities of power in such stream projects would be economic in the sense of salvaging a valuable byproduct of the necessary stream-control projects and would be economic also in the sense of facilitating the conservation of strategically important fuels.

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[13] National Resources Committee, *Our Cities—Their Role in the National Economy* (June 1937), pp. 29–30, 43, and *Population Statistics, 3 Urban Data* (October 1937) pp. 1–2. Refer also to "Competitive Development" in the next chapter.

The attention being given to storage in many of the water resources developments adds materially to the amount of dependable water power available. Such additional recovery of power will justify network extensions that could not be justified with respect to many projects designed with little or no storage. Meanwhile, the extension of network would make possible the development of many small waters, very useful for peak purposes, but not large enough, considered alone, to justify the necessary transmission facilities.

CHAPTER 5.—GENERAL COMPETITIVE RELATIONSHIPS OF WATER POWER AND FUELS

Developed water power, considered nationally, is quite predominantly used for generation of electricity. Undeveloped water power is appraised as a resource that may be used for the same purpose. Thus, the directly competitive position of water power resources must be considered with respect to the supplying of electrical energy.

Competitive Development

Use of water power in the United States is about as old as the industrial history of our country. Prior to the development of electrical transmission, however, power derived from falling water could be used only at the fall. The advent of the steam engine afforded vastly wider latitude for choice of industrial location, for the steam engine could be used wherever fuel and boiler water could be had cheaply.[14] Wood was available almost anywhere in the inhabited sections, and boiler water was available from either streams or wells almost anywhere back of the saline reach of tidewater. As lumbering, clearing for farms, forest fires, and use of wood for fuel caused here and there the beginnings of scarcity of wood, the canals and railroads made more distant wood, and (later) coal, available. Moreover, systems of public water supply made water more easily available. True, the building of roads, canals, and railroads gave easier accessibility to water power sites; and the introduction of the hydraulic turbine greatly facilitated the appropriation of water power. Meanwhile, goods manufactured at water-power sites could be transported to the markets also drawing from steam plants. But in most of the country the advantage was with steam power.

With the advent of electrical transmission, availability of the energy of falling water became technologically possible anywhere within reach of transmission from the power site; and from purely local availability that reach has spread so much that energy from a waterfall could be used a hundred, two hundred, and on toward three hundred miles from the fall. The same distances, of course, hold for a steam plant. But whereas formerly the choice was between water power at the fall only and steam power at numerous places, water power and steam have become alternative possibilities within transmission distance from the fall, i. e., say, somewhat over 250 miles (a tested distance) for a large power site.

Within reach of such radius a large hydroelectric plant might supply electricity anywhere within a circular area of about 200,000 square miles centered at the fall, i. e., an area approximately twice as large as the combined land area of the States of New York, Pennsylvania, and New Jersey, or considerably more than three times the area of all the New England States combined.

Thus within range of transmission from power sites water power is directly competitive with fuels as a source of energy. Moreover, even though energy from water may not practicably be used more than 200 or 250 miles from the power site, industry can gravitate into the orbit of a water-power site. Therefore, indirectly, water power is competitive quite beyond the economic limits of transmission.

Technically, fuels might be used to serve all the purposes served by water power. That is, technically, fuels could be used as a complete substitute for water power. Actually, during the post-war period when a tremendous expansion of electric utility capacity took place, increase of hydroelectric capacity was in approximately the same proportion as increase of capacity in fuel-electric plants. And it is significant to realize that this took place when very striking reductions were made by the utilities in the amount of fuel required per kilowatt-hour generated in the fuel plants.

General Range of Competition

The annual amount of water power available is large enough only to supply the smaller part of our present total energy requirements. We have noted earlier that the total of our developed water power, plus the undeveloped water power which appears to be probably feasible for future development, seems sufficient to

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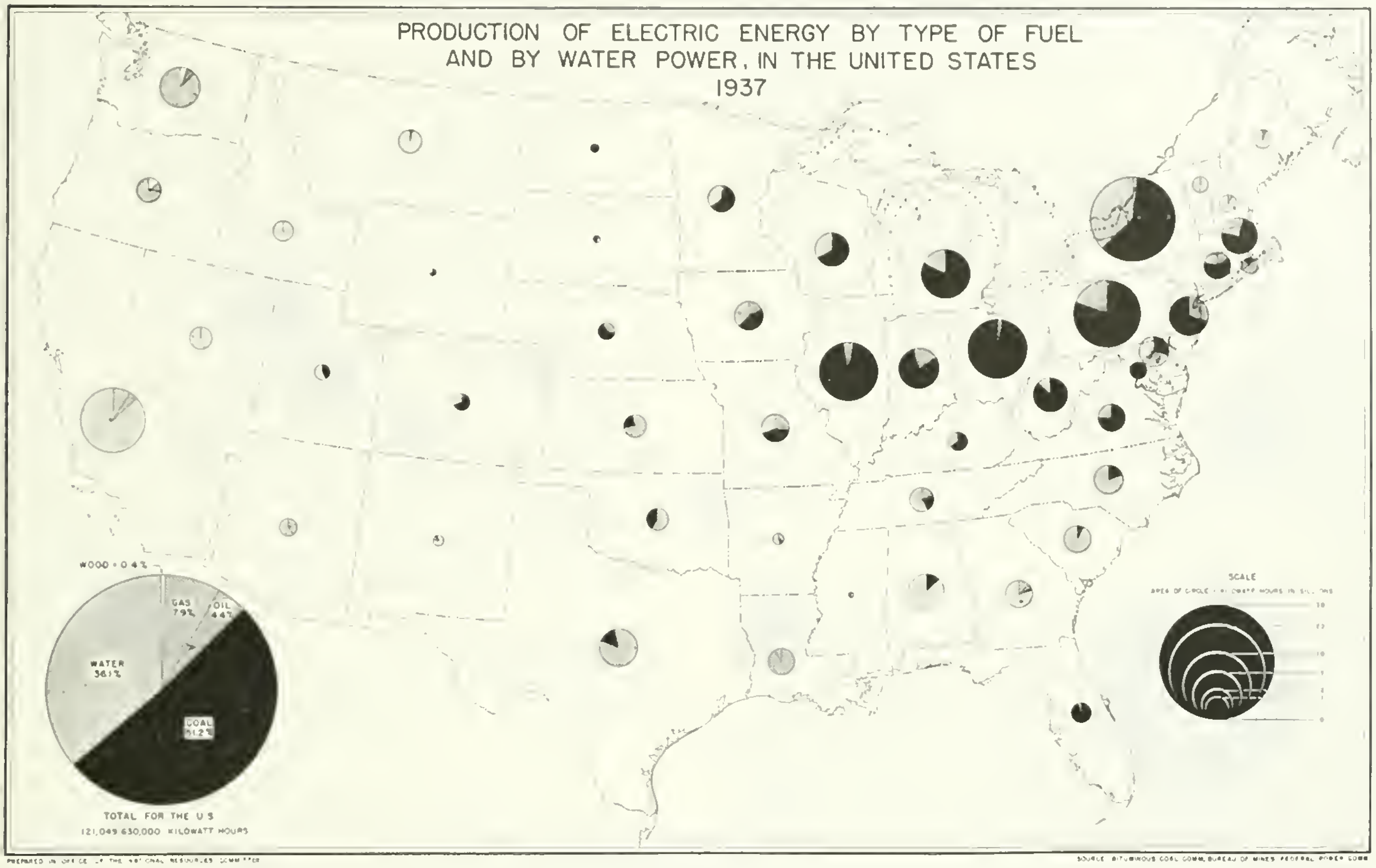
[14] On the early use of water power and later development of use of the steam engine, refer to C. R. Daugherty, *The Development of Horsepower Equipment in the United States*, U. S. Geological Survey, Water Supply Paper 579 (1928), pp. 24–28. On the general development of use of power, refer to John George Glover and William Bouck Cornell, *The Development of American Industries*, pp. 567–577.



PRODUCTION OF ELECTRIC ENERGY BY TYPE OF FUEL AND BY WATER POWER, IN THE UNITED STATES 1937

PREPARED IN OFFICE OF THE NATIONAL RESOURCES COMMITTEE

SOURCE: BITUMINOUS COAL COMM., BUREAU OF MINES, FEDERAL POWER COMM.

FIGURE 3.

supply an amount of energy equivalent to more than one-fifth, possibly one-fourth, of our largest past annual use of energy. Viewed in terms of our total use of energy, and with due regard for present technical and economic limitations, use of water power instead of fuel is seen to be possible within a comparatively limited range.

Very large proportions of our use of energy, however, are outright fuel requirements, i. e., requirements in which, for economic or technical reasons, electricity is not now acceptable. But many of these economic and technical limits are not of abiding character, and energy requirements formerly thought to be wholly or mainly direct fuel requirements are increasingly being met with electrical energy.

The larger the proportion of our use of energy in the form of electricity, the larger the technical latitude for using water power, within the limits of its availability. Our total use of electricity is not reported; but the larger part undoubtedly is generated by utility central stations, and that large part is reported. In 1937 more than 36 percent of the electricity produced by utilities was from hydro plants. The estimated annual output possible from undeveloped water power probably feasible for future development is estimated to be more than six times the output from utility hydro plants in 1937 and more than 5½ times the estimated total output of all water wheels in 1937, including those outside the utility group. The total output from water power probably feasible is close to 2.7 times the total output of the electric utility group from fuel and hydro plants in 1937. Such total feasible output probably is considerably more than twice as great as our total production of electricity.[15] Thus, within its field of use, namely, in the generation of electricity, potential water power has possibilities of very wide range.

In view of the great difference among regions in total energy requirements, in requirements for electrical energy, in fuel resources, and in water-power resources, the competitive position of hydro varies from region to region. Increasing relative use of electricity, relative

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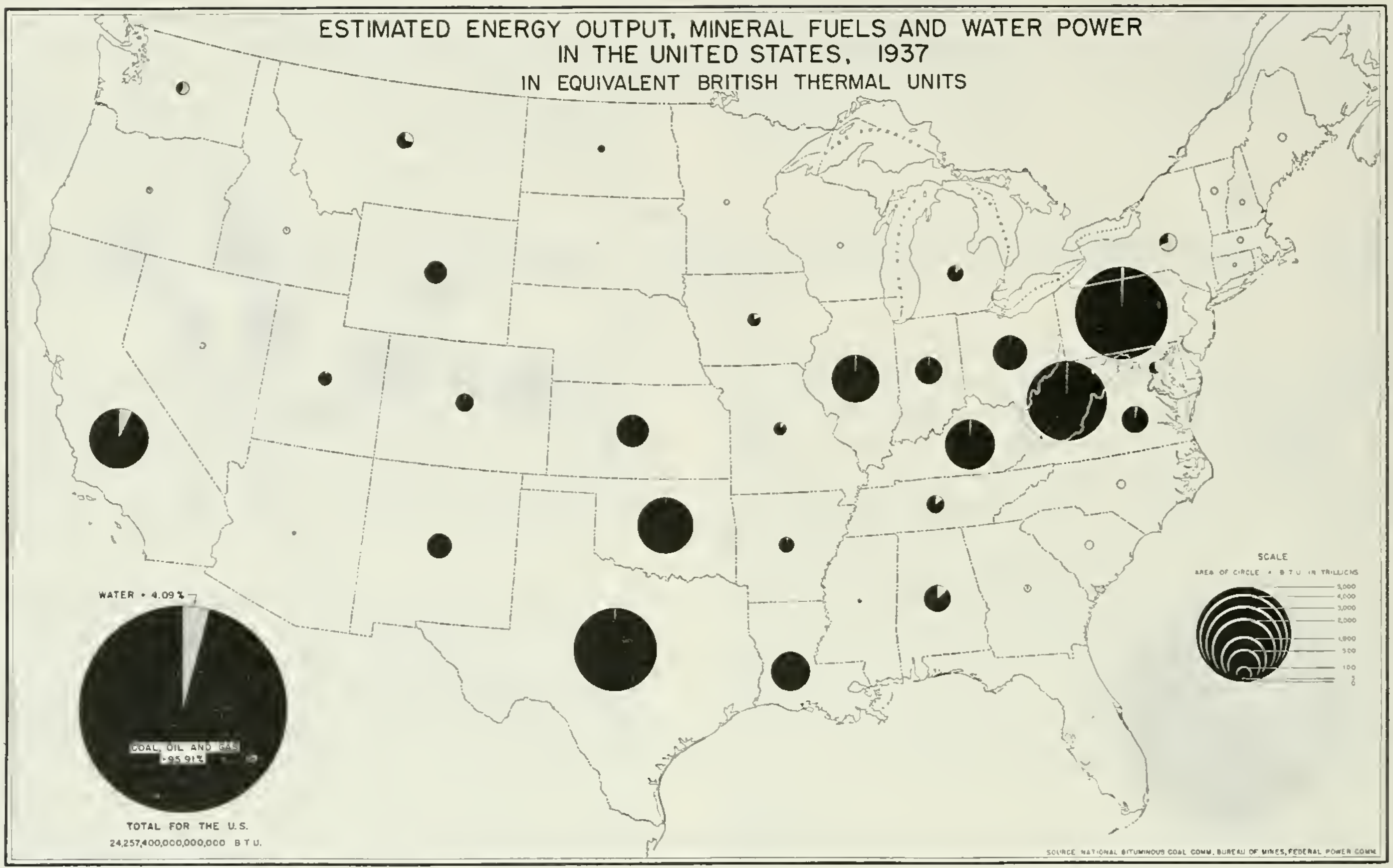
[15] Presumably the larger part of the generator capacity outside the utility group is in manufacturing and mining. For the end of 1929, the census showed generator capacity amounting to 8,530,364 kilowatts in manufacturing and mining combined. At the end of 1929, generator capacity in the utility group was 31,514,103 kilowatts, according to the Federal Power Commission. Specific industry loads, however, provide a much lower capacity factor than diversified loads of central stations. On actual utility output, estimated output of all water wheels, and estimated energy available from undeveloped water power, refer to tables 3 and 6.


ESTIMATED ENERGY OUTPUT, MINERAL FUELS AND WATER POWER IN THE UNITED STATES, 1937
IN EQUIVALENT BRITISH THERMAL UNITS

WATER • 4.09%
COAL, OIL AND GAS • 95.91%
TOTAL FOR THE U.S.
24,257,400,000,000,000 B.T.U.
SCALE
AREA OF CIRCLE • B.T.U. IN TRILLIONS
5,000
4,000
3,000
2,000
1,000
500
100

SOURCE: NATIONAL BITUMINOUS COAL COMM., BUREAU OF MINES, FEDERAL POWER COMM.

PREPARED IN OFFICE OF THE NATIONAL RESOURCES COMMITTEE

FIGURE 4.

exhaustion of regional fuels, and public policy regarding interconnection of power facilities, conservation of fuel, and development of water resources are likely to change these interregional differences in the economic position of hydro. Both the regional differences and the likelihood of changes in regional differences are to be kept in mind as qualifications of any tentative generalization about the general economic position of hydro.

Our energy requirements may be thought of in the broad classifications of light, power, heat, and specific requirements for electricity. In viewing the requirements for light, power, and heat we need to note both how great is the extent of likelihood that electricity will be used and whether the current required is likely to come from the central station of an electric utility. If it does come from a central power station, the comparative present importance of water power in meeting the requirement may be gauged roughly by reference to the relative magnitude of utility hydro output in the several States and regions.[16] Allowance should be made for the fact that the larger basin-unit projects completed or in process of construction—especially those of the Tennessee, the Colorado, and the Columbia—raise both the likelihood that the energy requirement will be met with electricity and the proportion of the electric requirement likely to be met from hydro plants.

Light

Electricity has unquestioned predominance for lighting. Within reach of utility transmission lines, far the larger part of the current for lighting is from central stations.

Some industrial plants and mines not reached by utility transmission lines have their own generating plants. The extension of utility networks has definitely reduced the proportion in this group. Some of the larger estates, farms, and dairies also have small generating plants, but they also tend to take their current from central stations as rural transmission lines are extended.

In transportation, for obvious reasons, current for lighting is mainly from fuel-driven generators. Occasionally large commercial or industrial establishments, for special reasons to be considered presently, may have their own generating plants and provide their own light.

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[16] Table 3 and figure 3.

Power

Domestic Power

Motorized household appliances are used very widely. Estimates indicate more than 10 million each of vacuum cleaners, washing machines, and electric clocks, and over 9 million electric refrigerators at the end of 1936. Radios (socket sets) were said to number over 21 million. Oil-burner appliances were estimated at 1,175,000. Energy used for appliances in 1937 (a smaller average number than that at the end of the year) was estimated at more than 10 billion kilowatt-hours, of which about 58 percent was for motorized items and radios, the remainder being for heating appliances. Refrigerators and radios reflect the normally greater continuity of use, the former being estimated to have used about 32 percent of the total appliance use and radios about 16 percent. The total load attributable to domestic motorized equipment and radios is larger than that attributable to domestic lighting, according to these estimates.[17]

Such domestic requirements, of course, are almost entirely met from central stations; and what was said above regarding water power with respect to lighting holds for the other domestic uses.

Power Requirements in the Commercial Buildings

The larger hotels, apartment buildings, stores, and office buildings commonly require power for elevators and for motorized cleaning equipment. Refrigeration constitutes an added requirement in hotels and apartments. A considerable and increasing number of the commercial buildings have mechanical stokers and some kind of motorized ventilating or air-conditioning machinery. In many stores one finds more or less use of cutting machines, grinders, mixers; and electric sewing machines are likely in the larger tailoring and altering departments.

In some very large commercial buildings the necessity of bulk steam generation for heating may make provision of light and power from the same plant more economic. But ordinarily the power requirements for commercial buildings will be supplied, along with lighting, from central stations.

Power for the Industrial Plant

Power for stationary industrial machinery is supplied in part from power systems constructed as part of the plant and in part by motors driven with purchased energy, usually purchased from central stations. Motors using purchased energy constituted a decidedly increasing proportion of the total installed horsepower in industrial plants in recent years. The latest census figure available on power equipment in manufacturing (that for 1929) showed more than half of the aggregate horsepower in that classification. In mines and quarries the proportion was not far below two-thirds. There is no doubt that electrification has increased greatly since 1929.

Some large industrial plants generate part or all of their own power. This practice often arises in connection with special heating requirements, to which we shall revert presently. Sometimes the special reason lies in the availability of great amounts of combustible waste, such as that of a large sawmill. Aside from these special considerations, a company may find the power available for purchase inadequate or too costly. But the company making such choice, unless it is free to locate at or near a water-power site, has not the same freedom that the utility company has in reaching water power, because of the lack of the right of eminent domain.

Power in Transportation

Electric street and interurban railways are numerous. A few steam railroads have outstanding electrified sections, and a large number have electrified portions of some importance. In 1936 the Federal Power Commission found 2,768 route-miles and 6,441 track-miles in electrified sections of steam railroads. Dense traffic, of course, generally characterized these electrified portions. The Commission reported that approximately 9 billion kilowatt-hours, about 11 percent of the electric power generated for public consumption, were used in transportation. Approximately one-sixth of this was used for traction purposes by the steam railways. Several thousand route-miles of additional electrification are considered feasible by the Commission, as are additional terminal electrifications.[18]

Technically, electrification might be applied to any of the railroads and to highway vehicles operating on schedules over fixed routes. Cost of railroad electrification does not usually seem justified except in dense traffic areas; but railroad electrification for less dense traffic may come to have wider appeal in large regions of scarce fuel and abundant water power, such as the Pacific Northwest. At present, most railroad traffic is drawn by steam engines.

Nearly all power vehicles for the highway and all airplanes are moved by internal-combustion engines. On the water most small power craft and many larger ones are propelled by internal-combustion engines. Far the largest part of the tonnage on the water, however, is moved by steam engines or turbines.[19]

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[17] *Edison Electric Institute Bulletin*, March 1937, p. 74.

[18] Federal Power Commission, *National Power Survey*, Power Series No. 4, pp. 1–21.

[19] At the end of 1937, ocean-going iron and steel vessels of 2,000 gross tons and over in the United States merchant marine aggregated 7,990,682 gross tons. The total classed as driven by reciprocating engines was 4,587,681 gross tons; that by turbine, including turbo-

Thus, transportation requirements for energy are predominantly fuel requirements. Although freight and passenger volume hauled with electric motors or likely to be so hauled is relatively large, in view of the dense traffic usually associated with electric haulage, much the larger mileage of railways, far the most of our highway traffic, and all of our water traffic (except, conceivably, in some narrow canals) will remain dependent on fuels.

An important point to be noted is that a very large proportion of transportation moves by the use of oil. Highway traffic in overwhelmingly the large part is carried by the internal-combustion motor. Of 43,624 steam locomotives in service on Class I railroads at the end of 1937, 6,548 were equipped with oil burners.[20] Most of our oceangoing tonnage is moved by motor, engine, or turbine, with energy from petroleum.[21] And the Navy, of course, also moves largely with oil as fuel. The strategic significance of oil and oil products for transportation and for the Navy is so great as to establish this use definitely as one of the preferred uses for oil.

Heating

Both in the home and in industry, the uses of electricity through heating units is increasing significantly; but the use of electricity for space heating is very limited, and its use for process heating is mainly restricted to processes for which high heat subject to close control is important. The reason should be noted. It lies primarily in the fact that even in the better generating plants only 25 to 30 percent of the energy in fuel is transformed into electrical energy. Efficiency of furnace and boiler in the typical central station is undoubtedly much higher than that of the typical heating plant in domestic, commercial, or industrial buildings. Heat losses from residences or commercial buildings probably more than offset the transmission losses. But a part of the process of operating the steam turbine typically involves an enormous loss (deliberate removal) of heat at the condenser, such heat ordinarily flowing out into lake or stream with the cooling water.[22] Where sustained ordinary heating is required, burning the fuel on the premises, even in a furnace much less efficient than that of the central station, will make more of the heat available than can under present methods be made available from a fuel-electric station over the electric transmission line.

If the available electricity happens to be from a hydro plant, the economic principle involved is not changed. Most of our electricity is generated from fuels, and the economic value of hydroelectric energy is properly calculated in terms of the cost from the alternative fuel source.

Domestic Heating Uses of Electricity

Heavy sales of domestic electric appliances have characterized the market in recent years. Mention was made above of the motorized equipment. There is no definite record of the number of heating appliances in use. The following estimated numbers of specified appliances suggest their approximate prevalence at the end of 1936:[23]

	Number	*Kilowatt-hours per year per appliance, normal use*
Flatirons	21, 750, 000	80
Toasters	10, 250, 000	30
Percolators	6, 000, 000	36
Space heaters	4, 500, 000	50
Ranges	1, 450, 000	1, 350
Ironing machines	1, 175, 000	125
Water heaters	432, 000	3, 000
Roasters	375, 000	250

The noticeable thing about most of these items is that they are used a very minor percent of the time: the flatiron and the ironing machine typically a few hours, perhaps a day, a week; the toaster ordinarily a few minutes at breakfast time; the percolator perhaps a little more. And the fact that the estimated average consumption for a space heater is less than twice that for a toaster reflects the limited use of the space heaters. Comparison of the average total domestic consumption of 700 to 800 kilowatt hours with the estimated requirement for the range or the water heater suggests reasons for their very limited use.

Estimates of use of energy through these heating appliances, given in connection with the figures cited, indicated that about 42 percent of the total energy for domestic electric appliances, including motorized items and radios, was used in heating appliances. Close to one-third of this heating total was for ranges, more than one-fourth for flatirons, and more than one-sixth for water heaters. Less than one percent was allocated to space heaters.

It is an item of definite experience that these appliance sales have constituted an important market and

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electric, 2,866,225 gross tons. U. S. Maritime Commission, *Ocean Going Merchant Fleets of Principal Maritime Nations*, Report No. 1100 (Dec. 31, 1937), p. 1.

[20] Interstate Commerce Commission, *Statistics of Railways of the United States, 1937*, pp. S–12, S–14.

[21] U. S. Maritime Commission, *loc. cit.*

[22] As an example of the significance of this loss, engineering estimates were presented in New England nearly 15 years ago indicating that in industrial plants operating generators the cost per kilowatt-hour was about half or less than half as much in plants making use of steam or warm water after use at the generator as at plants not doing so. Main, Charles T., Harriman, Henry I., and Jackson, Dugald C., "Power Requirements and Sources of Supply of New England," *Journal of the Boston Society of Civil Engineers*, Vol. XI, No. 5 (May 1924), pp. 203–204.

[23] *Edison Electric Institute Bulletin*, Vol. 5, March 1937, p. 74.

that with lower rates for electricity a definite stimulus is noted. The predominant sales and use in most sections, however, involve the occasional use, not sustained heating. The low rates offered in the Pacific Northwest will serve as a test on enlarged use of electricity for sustained heating purposes in the home.

Wood is used for domestic heat in many rural sections and even in certain urban sections to which wood is easily available and comparatively cheap in relation to cost of mineral fuel. In terms of the bulk national market, however, the major fuels for domestic heating are coal (and coke), oil, and natural gas.[24]

Commercial and Industrial Heating

With little exception, space heat for commercial or industrial buildings, like that for the home, must be had from fuels. In a relatively limited number of large commercial establishments, the operation of a generating plant in connection with the heating plant is found economic. More frequently the large industrial plant, having to deal not only with space heating, but also with process heating, finds it economic to generate electricity for its own light and power, and possibly also for electrical processing. Even smaller plants having relatively large requirements for steam for processing purposes often find it economic to generate steam at a pressure adequate for operation of a turbine and use the steam for generating electricity on its way into the heating pipes. Such special instances of the generation of electricity as a joint-product with, or a byproduct of, heating are mentioned because they often constitute important limitations on the use of central station power. A kindred limitation is found in those plants having large amounts of combustible waste suitable for heat and for generation of power.

For industrial heat-processing as a whole, the main dependence is on fuel. Marked advance, however, has taken place in use of electricity in electrothermal processes. Manufacturing groups chosen to represent the large users of electricity in processing were reported to have used close to 12 billion kilowatt-hours in 1936, of which a total of about 5.6 billions appears in the classification "electrothermal" and the separately shown items for electric furnace iron and electric heat treating.[25] Such total is equivalent to approximately 5 percent of the electricity produced for public use in 1936. Energy not for public use, i. e., not from central stations, is, of course, included. The ratio probably is closer to 4 percent of the total use of electricity in 1936.

Summary and Interpretation of Competitive Relationship

Water power is best used in the production of electricity, and nearly all the developed water power is so used. Primary competition of water power with fuels, therefore, relates to the demand (and more likely potential demand) for electricity. The residential market for electricity is for general lighting, for power in widely prevalent motorized domestic equipment, and, with the exception of a few sections, for relatively minor cooking and space heating. The commercial and industrial market is for lighting, power for stationary machinery (some mobility within the plant is recognized), possible limited space heating, and electrical processing. Because of the ease and increasing practice of substituting electric motors for steam power in industrial plants, the increasing importance of electrical processing, and the increasing relative dependence on central stations, that portion of the energy market in which water power may be the source, instead of fuel, is enlarging.

Competition of hydro with fuel-generated power, of course, also means competition with the production of coal, oil, and natural gas. (The only considerable use of wood for steam-raising is in the great lumber regions, the wood fuel being waste.)

In net national effect such competition with fuels has meant not so much actual displacement of fuels as the limitation in the increase of fuel use; in some sections there has been positive displacement. If it is to be supposed that competitive adjustments have been made to the costs of the several types of fuels, such displacement would merely strike at the fuel plants in the weakest market position with respect to relative cost of electrical energy from fuel. This does not necessarily mean the plants that are technologically least efficient. Presumably the very growth in the use of oil and gas has reflected a market preference, competitively considered. It is not reasonable to suppose, therefore, that water power in the areas burning some of each fuel would, acting alone, selectively displace high-grade coal, oil, or gas. A discussion of this point appears in chapter 6, under the heading, "Water-Power Policy and Fuels Policy."

Geographic selection probably would mean something. For example, water power near the Atlantic seaboard might displace a substantial amount of fuel oil, as well as coal; water power in the middle south and in the southwest might displace much oil and gas, as well as coal; water power in the Pacific section would displace oil and gas mainly.

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[24] For instructive data on residential fuels in urban areas, refer to the following: U. S. Department of Commerce, Bureau of Foreign and Domestic Commerce, *Real Property Inventory—1934, Summary and Sixty-Four Cities Combined.* Bureau of Business Research, University of Pittsburgh, *Real Property Inventory of Allegheny County* (which shows Pittsburgh and other political subdivisions in the county separately and is tabulated by census tracts). Philadelphia Surveys, *Report of Philadelphia Real Estate Survey, 1934.* New York City Housing Authority, *Real Property Inventory, City of New York.* Federal Emergency Relief Administration, *The Bituminous Coal Industry, With a Survey of Competing Fuels.*

[25] Refer to Federal Power Commission, *Power Requirements in Electrochemical and Electrometallurgical and Allied Industries* (1938).

A genuine conservation policy for oil, gas, and high-grade coals, however, cannot be left to hang on geographic accident. A positive fuels policy must accompany a water power policy.

CHAPTER 6.—DESIRABLE ELEMENTS OF PUBLIC POLICY ON WATER POWER

The term "public policy," as used here, means the general cast and direction of public action through government. The question "What public policy is desirable with reference to water power?" means "What should our Government do about water power?", which, in turn, means "Toward what broad objective should our Government aim with respect to water power?" and "What general character of action seems most likely to lead toward that objective?" In view of the Federal composition of our Government, decision on character of action necessitates decision on allocation of responsibility, and of authority in keeping with that responsibility, between the Federal Government, on the one hand, and the States on the other.

General Orientation

Production of power from falling water is an economic activity, whatever its other characteristics and impingements. Part of our economic activity is carried on by government. Construction and maintenance of highways would be accepted as an obvious example. Generally, however, we consider that the larger part of our economic activity is carried on by private enterprise. Toward private enterprise, there are many kinds of governmental actions representing many degrees of intent to restrain and many degrees of intent to encourage. To illustrate the range, we seek to restrain or to abolish the private enterprise of selling fraudulent securities, but we seek by positive and rather costly means to encourage the industries of aviation and ocean shipping.

In the field of water power, existing public policy includes the whole range from prohibition of developments that might interfere with other policies, through regulation of private hydro development, to outright public ownership and operation of water-power plants. The policy problem arises, presumably, because such range encompasses incongruity and conflict or because it is not adapted to new objectives. To arrive at a new policy might mean curtailment of the existing range of policy. It might mean a much greater emphasis at some points in the range, the effect of such increased emphasis being to subdue or to eliminate some aspects of existing policy.

In formulating a judgment on the desirable kind of water-power policy, we shall reduce the probability of error if we keep in mind: (1) that energy is only one of numerous economic requirements; (2) that water power is only one of several important sources of energy; and (3) that use of falling water as a source of energy is only one of several important uses of the water running in our streams.

Regarding the first of the three items, only its general implications lie within the scope of this report. First, an energy resources policy is no cure-all. Second, any energy resources policy must be weighed at the outset and continually reweighed in terms of its consistency with broader economic policy. Governmental policies on economic matters extend through a long record of tariffs, land grants, subsidies, protective legislation for weaker groups, prohibitory legislation against economic malefactors, controls over money and banking, and special tax measures. Furthermore, such measures are attacked or defended in terms of their injury to or promotion of the broad economic interest. To ask that an energy resources policy be viewed thus in terms of the national economy is but to ask enlightened extension of very old practices of judgment on public matters.

The other two items will be considered separately, in the following sections.

Water-Power Policy and Fuels Policy

The general competitive relationship between water power and fuels has been reviewed in chapter 5. Water power may displace fuels in the generation of electricity, either directly through causing the shutdown of fuel-electric plants, or indirectly through forestalling the expansion of use of fuel. This fact underlies the logic of developing water power as one means of aiding in the conservation of scarce fuels.

In view of the threat to our supply of oil, gas, and high-grade coals, it is probably not enough to seek merely to prevent increasing use of these scarce resources. An effective conservation policy seems rather to call for positive curtailment of their use. But active development of water power would not selectively displace only the fuels we wish to conserve. It would displace some of all fuels; and the fact that oil and gas have noticeably displaced coal indicates that, under existing market circumstances, coal often is marginal and often would be displaced first. Therefore, to whatever extent water power is meant as an aid in conservation of scarce fuels, the water-power policy must be accompanied by policies aimed positively at restraining the less economic uses of scarce fuels.[26]

Water Power and Other Water-Resources Problems

Meanwhile, control of water resources cannot be merely a water-power problem. Power production from streams must be handled with due regard for flood control, navigation, soil conservation, irrigation, water supply, pollution abatement, and other special uses of water.[27] Not all these problems are found in every stream, but two or more are likely to be found in even minor streams, and most or all are probable in the great rivers. Both complement of purpose and conflict of purpose lie in this array of water problems. For example, water storage in rainy seasons for release in drier seasons may reduce destruction by flood, increase firm power, maintain depth of water for navigation, assure continuity of public and industrial water supply, and, through limiting relative pollution in dry seasons, maintain a better quality of water supply. On the other hand, use of too great a proportion of possible water-storage space to increase power, to facilitate continuous deep-water navigation, or to increase possible irrigation will leave insufficient storage for flood control.

These relationships will be noted with more care presently. For the moment, the purpose is merely to demonstrate that water-power policy, already seen as inevitably related to other parts of our energy-resources policy, also is inevitably related to other aspects of our water-resources policy.

Multiple Purpose and Basin Unit

Without storage of water in times of larger run-off, the maximum of normal firm power is set by the minimum of normal stream flow. In a humid section, 50 or 60 percent of the annual run-off may be of intermittent rises or floods; in some of the arid western sections where streams are fed mainly by thaw of snow in the mountains, 75 per cent of the run-off may pass as a great wave within a comparatively small part of the year.[28] These great swells of water are useless for power, except to the extent that they are caught in reservoirs and held back so that their use can be synchronized with load requirements. Indeed, they may seriously interfere with power production by raising the water level on the downstream side of the dam and reducing useful head during the periods of high water.

We have noted in an earlier section that potential horsepower measure by arithmetic mean flow was estimated in 1936 at about 3⅓ times that measured by low flow, after allowance for the lift of low flow by existing storage. Without for the moment contending over the advisable extent of storage, we may readily conclude that great additions to firm power are physically possible through storage and controlled release of the run-off in streams.

Power production, however, is only one of the purposes of storage. Prior to 1930 most storage reservoirs were each for a single primary purpose. Aside from power reservoirs the more usual purposes were public water supply and irrigation. In addition, a number of temporary storage, or retarding, reservoirs had been built for flood control, such as those on the Miami River in Ohio. There were also some projects of storage for navigation, such as those associated with the Erie Canal. Since 1930 there have been several projects for huge multiple-purpose reservoirs in extensive basin plans.[29] Lake Mead (Boulder Dam) is an example of the super reservoir of multiple-purpose type. Norris Lake is part of a multiple-purpose series. These projects are of the basin-unit type; i. e., they each involve practically a whole stream and its major feeders. Why multiple purpose? Why basin unit?

Each of the single-purpose types of storage reservoirs mentioned above is for the purpose of some control of stream flow. Storage for power, for navigation, or for flood control results in reducing flow at certain times and in increasing it at other times. The timing of release for power or for navigation at upstream reservoirs has compulsory influence on the timing of uses downstream.

Storage for water supply or for irrigation is for diversion. It reduces flow at some times but never provides a later compensating flow. Such projects, therefore, affect the timing and reduce the total availability of water downstream.

Storage for flood control is merely for purpose of retardation. If the time of release is not coordinated with other releases, natural or controlled, upstream or downstream, it may increase the catastrophe of flood.

Any storage reservoir floods an upstream area. It bars any other dam in the flooded area. It limits the height of any other dam for some distance downstream. And choice of a suitable storage reservoir site is, in effect, appropriation of a natural retarding basin—a wide bowl with a narrow throat at the downstream side. That is, a storage reservoir in a good site but without supplementary storage provision for flood control may increase the catastrophe of flood.

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[26] Such policies are discussed above in Section I on coal, and Section II on oil and gas.

[27] National Resources Committee, *Drainage Basin Problems and Programs* (1937 Revision), p. v.

[28] W. G. Hoyt, *Water Storage in the United States as of January 1938*, U. S. Geological Survey (Preliminary mimeographed report, subject to revision), p. 2.

[29] *Ibid.*, pp. 2–38.

Any dam without locks is a bar to navigation and to the floating of timber. Also, without special passageway, it is a bar to the passage of fish.

In short, a significant storage reservoir in any important stream is inevitably a multiple-effect project. The only conceivable method of reaching the most beneficial—or least harmful—set of multiple effects in use of our water resources is to design and operate the controls in terms of the several necessary or desired objectives, i. e., as multiple-purpose projects.

The coordinated designs and the controls of a multiple-purpose project inevitably relate to the main stem of a stream and to its principal feeders. That is, most, or all, of the basin is involved. Hence, the multiple-purpose project must be designed in terms of the basin or subbasin unit.

Clearly not all basins and subbasins will soon be so developed. But partial public development or grants of privilege for private development should be such as to fit into, or to interfere as little as possible with, future multiple-purpose, basin-unit designs.[30]

Power in the Multiple-Purpose Project

The essential logic of a basin-unit system is that of coordinated regulation of stream flow through storage and controlled release. Storage, no matter for what main purpose, creates a head of water. Except in the instance of conflict of use for power with a more urgent purpose, head of water represents at least a possibility of power. Probably it would be admitted that in most basins a substantial part of the storage may legitimately be for the primary purpose of power. What of power from projects with respect to which some other purpose is primary?

The most obvious and most discussed conflict of purpose in use of water resources relates to flood control and power. Since flood control is of great urgency in so many basins, one may appear to demolish all concept of wisdom in production of water power by the pat observation that an empty reservoir will not run turbines and a full reservoir will not catch floods. With respect to a particular reservoir, the observation is in point, but it is not thereby conclusive. That one reservoir might be reserved for flood control and another on the same stream used for power probably stumps no one. Neither should it stump anyone that part of a single reservoir be reserved for flood and part be used for power. Indeed, it would often cost less to provide flood-control space in the same reservoir with power space than to build a separate reservoir. And it should not be forgotten that storage to prevent the ordinarily low flow of dry seasons is itself flood prevention in that better sustained ordinary flow tends to maintain clear channels. If the conflict really were irreconcilable, we should be forced to abolish private water-power plants on every stream system requiring flood control. If private power and public flood control may harmonize, one may believe the same of public power and public flood control.

There is no conflict of purpose whatever in running public water supply, irrigation water, or navigation water through a turbine during the periods of release from storage. Granted that a primary purpose other than power may determine quantity and periods of continued release, nevertheless such release may provide a considerable amount of economic power. In the instance of headwaters storage aimed at general assurance of summer flow, the release may provide extra power when, because of scarcity and high temperature of cooling water, fuel-plant costs are higher. But particularly relevant is the fact that in the multiple-purpose scheme, including power installation, whatever water must be released for downstream purposes may go through the turbines, either adding to total available power, if needed, or reducing the storage allowance necessary for power.

In short, there is no irreconcilable conflict in the basin unit plan between flood control and power production; and nonpower primary purposes other than flood control may dovetail to a great extent with power production. The essential logic of the multiple-purpose basin-unit stream-control plan, therefore, clearly permits considerable allowance for power production; and power development, providing substantial offset in cost of stream control as well as facilitating conservation of fuels, is economic and wise.

Federal Power Production

The use of water for power production is inextricably interwoven with other uses of water resources. The multiple-purpose plan seems undoubtedly best suited to basin solutions of water problems. No flood control of consequence has been effected by private business. Many power companies are interested in water power, but as power companies they cannot on a business basis handle the other water problems. Public utility water companies are interested in public water supply but cannot handle other water-resources problems on a business basis. Rarely has a stream been much developed for navigation on a private basis. No merely private operation will take care of pollution. Irrigation developments of the more successful sort are quasi-public or outright public projects. What all this sums up to is that, judged from experience, only a limited part of the needed development of a stream may be expected from private business. In other words, while private business has done well some things in the field of water resources, nowhere has private development handled all of the things needed; and often what has been done privately was in conflict with other proper utilization of water resources.

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[30] A provision in that general direction was enacted in 1920: *Federal Water Power Act*, Sec. 7.

Much that must be done with streams, therefore, must be done by government. Since doing the job as a unit seems best, and since government must do part of it, government must carry on with the multiple-purpose development. But what government?

Most of the important streams are interstate streams, which is to say that most major streams reach beyond State jurisdiction. A State can do significant work in intra-State subbasins or on a main stem segment within the State. But no such development of significant effect on stream flow could go forward without a coordination of the different State works. Interstate compacts have not proved widely effective for positive accomplishment. With respect to interstate streams, then, the conclusion seems inevitable that coordinated, economic development is utterly impossible except in terms of Federal basin plans.

Federal Basin Plans and Older Public Stream-Control Works

Basin-unit schemes under way are both recent and few. Every significant stream in the country, however, already has some works, public or private, for control and utilization of water. Federal drainage basin plans, therefore, must provide for dealing with these older works. Private works will be reserved as a special case for the following section. The older public water-control works will be considered here briefly.

River works of the Federal Government, until very recent years, have related primarily to navigation, irrigation, or flood control. How much of either we should have is subject to debate. But we do have works for such purposes and the tendency is to increase them. And it is hardly debatable that these purposes can be served better by coordinated water-control plans than by isolated works. In other words, while adaptations or replacements will no doubt be necessary, these older Federal works are no grave obstacle to basin planning.

Some States or localities having works for similar purposes may object to having their works merged into larger plans. Such merger may not always be necessary; but, if it is, the essential promise of better performance justifies assertion of the Federal power over navigable streams.

Local works for water supply are numerous and more will be needed. But one of the major purposes of far-reaching stream control is the undebatable purpose of assuring a more abundant public water supply of better quality. No conceivable public plan, therefore, is in conflict with the purpose met by a municipal water-supply reservoir. If a particular reservoir were structurally out of harmony with a basin plan, it would be so only because the plan provided for more storage, rather than less, at the site.

In the Pacific section, there are some important municipal water-power plants. In the area of the hydro plants supplying cities on Puget Sound, the one other major water problem is flood control. Part of that control would be provided by additional storage to guard against summer shortage of water and increase the year-round assurance of power. Additional flood control is possible with retarding basins in no wise in conflict with the public power plants. In California, thoroughgoing water controls are needed for public water supply and for irrigation. Extensive storage for these purposes would aid materially toward the flood control which is badly needed in spots. Meanwhile, increased power from such storage would be quite in line with the need to check the prodigal use of gas and oil.

In short, it is hardly possible to find conflict of purpose between older public water-control works and coordinated plans to serve the same purposes better. But for older works structurally at odds with a better plan, a bold policy of adaptation or of replacement is to be commended.

Federal Basin Plans and Private Water-Power Plants

Multiple-purpose projects of basin-wide scope will, in most instances, involve dealing with private water-power plants already in the streams. Structurally, a private dam and reservoir, remaining private, would prevent the erection of any dam in the private reservoir area; and it would set a definite limit on the level of any reservoir constructed on the downstream side. Operatively, to prevent jeopardy to the operation of the private plant would set a distinct limit on the volume pattern of upstream storages and releases and would set a limit on the level attained by downstream storage or flood retardation. In smaller tributaries and headwaters the effect would be at least to prevent the best design for storage and flood retardation. In the main stem a private plant not only would be able to dictate a major limitation of design but also would be able to set distinct limits on operation of water controls in the neighboring downstream sector and for the whole upstream part of the river system.

At the same time, maintenance of its strictly private character would prevent realization of the full economy of interconnected operation of hydro plants.

While constituting an obstacle to the best basin-unit design and operation, the private plant would be in a position to appropriate the increased useful power made available by public storage upstream for regulation of flow downstream. It seems doubtful that the legal provision for assessment for such benefits would prove to be a satisfactory remedy.

We have noted previously that private business cannot be expected to do the several things other than power production that must be done in economic control and use of water resources. Here it is necessary to add that preservation of existing private interest in water-power plants probably would often be essentially in conflict with the multiple-purpose basin-unit plan. Thus, if the elementary aims of a comprehensive water resources program are to be attained, the policy toward private water-power plants whose separate private operation is at odds with the more economic basin plan should eventually be that of purchase and absorption into public hydro systems.

Policy of Active Water-Power Development

Most of the preceding policy considerations sum up broadly to the effect that whenever water-power developments are undertaken, they should be governed by, or shaped in the direction of, designated lines of public policy. There are excellent reasons, however, for a positive Federal policy of developing water power.

The most compelling reason for such a policy lies in the need for conservation of petroleum, natural gas, and high-grade coals. Our use of these things has been, and continues to be, so prodigal that the pinch of restricted supply and, therefore, of rising costs, can hardly be far ahead. That pinch cannot be permanently avoided, but it can be long postponed.

Water power, so far as we can judge, is in practical terms a permanent resource. Use of water power as a source of energy, therefore, is a sane step in the conservation of petroleum, natural gas, and superior coals. To be sure, active development of water power without active measures to conserve the scarce mineral fuels will not be very effective in conservation. But no such one-sided policy is recommended. That water-power policy is inevitably a fuel policy has been emphatically recognized in preceding pages.[30a] That use of water power can be an important aid in conserving special fuels is obvious.

Certain aspects of this conservation need are directly related to the problem of national defense: oil-burning battleships; gasoline-driven airplanes, trucks, and tanks; metallurgical coke. One need not dwell on such unquestioned defense needs. But water power has another key significance in national defense. The defense angle of interconnection of power plants has been discussed in a preceding section. Water-power plants are of vast importance, even if consideration be restricted to the sheer fact of geographic continuity of power interconnection that will prevent power shortage in strategic centers in time of war. Beyond this, however, the more water-power plants we have to lean on, the less likely we are to be hamstrung by fuel shortage in time of war. It hardly requires demonstration that maximum practical use of water power in time of war would lighten the demand for labor in mining, transportation, and the utility industry.

Fortunately, we have been and hope to be at peace most of the time. When not at war or not seemingly threatened, we may think of an active water-power policy in relation to some of our internal ills, which might easily turn out to be more destructive than any external foe. The grim facts of wholesale poverty and unemployment in a Nation of our resources do not make social sense under any sane definition. Cheaper living and more opportunity to earn it are essential. Cheaper electricity is an essential for those attainments. Public development of water power is one method of getting generally cheaper electricity.

Aside from reasons for development of water power as a primary aim, it is hardly in point to forget the possibilities of joint-product or byproduct power from projects whose primary aims relate to other problems. Except the temporary retarding of run-off in flood control works having no other purpose, the solution of the various water-control problems require storage and controlled release of water. Storage creates head, and head of water released for any downstream purpose can be used to turn turbines when it is released. Meanwhile, storage requires dams; and, if dams must be built, the additional cost of providing for and installing electric generators is not relatively large. And a policy of active development of water power should embrace the best practicable use of power made incidentally available in works not aimed primarily for power.

Steam-Driven Plants in Connection With Federal Hydro Plants

From past experience with hydroelectric plants, the judgment prevails widely that the most economical development of water power is in conjunction with steam plants. The reasoning back of that judgment is that, although hydro has been very useful in many sections for peak demands, the normally low flow of streams at certain seasons has made it necessary generally to carry base loads on steam-driven generators. For an isolated system, with hydro capacity not regularized by storage (or by an unusually sustained natural stream flow like that at Niagara), the steam-driven capacity had to be sufficient to carry not only the base load the year around but also most, if not all, of the peak load during dry seasons. Consequently, the isolated system could not economically develop water power unless the resultant savings from part-time operation of hydro plants, largely or totally closed down in dry seasons, would justify a duplication of a substantial part of the generating capacity of steam plants. Because of differences among regions with respect to wet seasons, dry seasons, and load characteristics, part of the shortcomings of irregular water power are overcome by interconnection of water power plants. Here and there, use of storage has lifted firm hydro power well above the low flow, increasing the magnitude of base load that could be carried on hydro plants and decreasing the degree of dependence on fuel plants. But storage has not been used to a great extent until recently.[31] In other words, the firm power available through hydro plants has not generally been lifted much above that available at normal low stream flow. Of course, such plants were economical only in conjunction with steam plants.

[30a] Fuel resources, the problem of scarce fuels and the elements of a fuels policy are discussed elsewhere in this report, by Glenn E. McLaughlin (on oil and gas) and Wilbert G. Fritz (on coal).

There is large firm power provided in such designs as those of the Federal hydro projects on the Colorado, the Columbia, and the Tennessee. In the Pacific coast area, minimum dependence on steam plants is exactly in line with the national need to check the great consumption of gas and oil for steam raising in western utility and industrial plants. Even for the Tennessee Valley, in spite of abundant coal in the same region, careful development of firm power may well be in point because of the prodigal use of gas and oil in neighboring areas.

But the relation of fuel plants to hydro plants in the attainment of system balance cannot be judged merely in terms of those areas in which there are special reasons for extraordinarily large water storage and unusual opportunity for such storage. In many basins, the best practicable use of storage and of plant interconnection will not eliminate the cramping effect of low flow in dry seasons. In most instances, the immediate or eventual base load is likely to be beyond the firm power capacity of a strictly hydro system. Dependence on steam plants will remain; and where such dependence remains, the economy of at least part of the base load on steam plants and fluctuating load on hydro will still hold true.

Economical operation of the tie-up of steam plants and hydroelectric plants requires control in one set of hands in any one regional system. The objectives justifying Federal development of streams—both the objective of active development for cheaper power and the objective of developing storage for nonpower purposes—could hardly be served if the Government hydroelectric plants were turned over to private utilities. Attainment in the direction of those objectives, therefore, seems certain to necessitate a Federal policy of building or buying necessary fuel plants wherever the hookup of Federal hydro plants with steam plants is an economic requirement. Clearly, such building or buying should not operate to focalize unjust penalty on the regional private interests displaced. The cost of national policy should be nationally distributed.

Summary on Policy

An active public policy of multiple-purpose development of water resources is desirable, in view of the pressing character of problems related to flood control, public water supply, stream pollution, irrigation (in the West), and navigation, and in view of positive reasons for public development of water power. An active policy of public development of water power is likewise desirable. Both development directly for power purposes, where there is no conflict with more urgent water control, and the best feasible use of head made available by storage for other purposes would contribute toward the attainment of three major national objectives, namely:

(*a*) Conservation of scarce fuel materials—petroleum, natural gas, and high-grade coals.

(*b*) Strengthening the national economy through bringing about cheaper electricity more widely available.

(*c*) Strengthening the national defense, through better assurance of ample electrical energy in time of war.

Multiple-purpose plans for stream development aimed at the several important purposes, including direct or incidental power production, should be designed and executed in terms of drainage basins or major subbasins. Efficacy of controls requires dealing with the main stem of a stream and with all important tributaries. The Federal Government should have primary authority and responsibility for the design and execution of these multiple-purpose drainage basin plans for development and conservation of water resources. Private business firms cannot be expected to undertake the several important nonpower functions which cannot yield salable products. Moreover, private business firms cannot be expected even to bring about the most economic development of water power, because the necessary storage does not seem to be generally justifiable for power alone. State and municipal projects that harmonize with Federal design are quite possible and to be expected; but because of the interstate character of most of our important streams and the international character of some, State jurisdiction is too limited for the drainage basin plan.

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[31] Among our all-purposes storage reservoirs having 20 thousand or more acre-feet of capacity each, those completed since 1930 and those under construction at the beginning of 1938 will provide as much storage as all those in existence in 1930. Hoyt, W. G., *op. cit.* p. 40.

Federal policy should, in general, embrace eventual purchase and absorption of private water power plants where separate private operation conflicts with a more economic basin plan. Preservation of such private interest in a stream would usually prevent both thoroughgoing design and the best coordination of water controls. Federal policy on development of water power should embrace the building or the acquirement of steam plants in connection with any hydro development needing steam-driven capacity for sound balance of system capacity. The location of such plant need not be in the immediate basin area, for the same plant properly placed might serve as the steam supplement of two or more basin hydro systems.

Design of the power system in any of the basin developments should include, in accord with the best technology of power transmission, the best practicable interconnection: (*a*) of the several plants within a basin system, (*b*) with neighboring basin systems within the reach of economic transmission, and (*c*) with the steam capacity built or acquired to balance capacity.

PART TWO—SECTION I
FUEL RESERVES OF THE UNITED STATES

CHAPTER 1.—COAL RESERVES

By T. A. Hendricks*

Coal supplies more than half of the total energy used annually in the United States, although the rapid increase in use of petroleum and steady increases in use of natural gas and water power since 1900 have reduced the percentage of energy supplied by coal from about 90 in 1900 to about 57 in 1936. (See fig. 1.) In addition, our coal reserves constitute about 99 percent of the total energy that is derivable from all of the proved reserves of mineral fuels in the United States. Accordingly, the adequacy of our coal reserves is a matter of real national interest. Fortunately, they can be determined with a relatively high degree of accuracy that is not possible in determining the total resources of petroleum and natural gas, which are to a certain degree unpredictable. The adequacy of the coal reserves, however, is dependent on unpredictable future changes and increases in utilization to a far greater degree than on such known factors as present and past rates of production. As the supplies of oil and gas from natural reservoirs diminish, the large future source of energy now supplied by both oil and gas will lie in part at least in the great reserves of coal. Another important factor that may further increase the demands on our coal reserves is the rapid depletion of coal of high rank and quality in many foreign countries. Such increased foreign depletion may result in increased exportation of coal from the United States. Therefore, the future demands on our coal reserves are not quantitatively predictable but may be assumed to be far in excess of the maximum production for any year in the past (678,211,904 net tons in 1918).

The life expectancy of our coal reserves has been variously estimated to be as great as 4,000 years and as little as a few hundred years. The probability is that it lies between those two extremes. Even if coal should be called upon at some time in the future to supply the demands now met by oil and gas, the coal reserves of the United States would last about 2,000 years at the maximum rate of consumption of energy from mineral fuels in the past (approximately 23,400 trillion B. t. u. in 1929) and assuming a 30 percent loss of coal in mining.

Past and present mining of coal has been for the most part confined to the more easily accessible and higher quality coals. Thus, the percentage depletion of our total coal supply is of less immediate concern than is the much more rapid depletion of our high quality coals, such as the coals of the East that are suitable for metallurgical coke.

TABLE 1.—*Estimated coal reserves of the United States*

[Net tons and billions of B. t. u.]

Rank of coal	Reserves in net tons [1]	Average B. t. u. per pound	Reserves in billions of B. t. u.
Anthracitic	15,415,602,000	12,700	391,556,290
Bituminous	1,407,808,291,000	13,700	38,573,947,173
Subbituminous	818,083,894,000	9,500	15,543,593,986
Lignite	939,457,443,000	6,700	12,588,729,736
Total	3,180,765,230,000		67,097,827,185

[1] See table 3.

Advances in the efficiency of utilization of coal as well as other fuels have acted to prolong the life of the national reserves, and it is probable that future advances in mining technique and utilization will extend

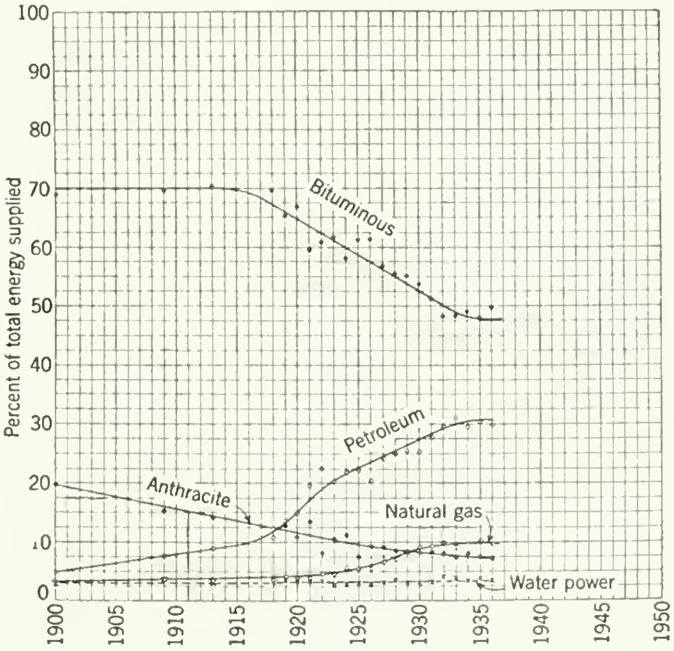

FIGURE 1.—Percentage of Total Energy Supplied by Mineral Fuels and Water Power (After A. C. Fieldner). Prepared by the Geological Survey, Department of the Interior. Data from Coal Economics Division, Bureau of Mines. The fuel equivalent of water power is taken at the prevailing average of all central stations for each year, declining from 6.45 pounds per kilowatt-hour in 1902 to 1.44 pounds in 1936.

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*Geological Survey, U. S. Department of the Interior.

the expected life of our coal reserves even further. The degree to which such advances will offset increased demands for coal in the future is not predictable, and it is probable that some technologic advances will even result in the application of coal to entirely new uses, thus increasing the demands on our reserves.

Because our coal reserves constitute a great future source of energy, their production and utilization is a problem of major importance to the future of the country.

Coal Reserves of the World

According to the latest estimates[1] the coal reserves of the world, by continents, are as follows:

	Net tons
Americas	5, 627, 823, 500, 000
Asia	1, 410, 487, 600, 000
Europe	864, 412, 600, 000
Oceania	187, 842, 900, 000
Africa	62, 755, 900, 000
Total	8, 154, 322, 500, 000

The United States claimed 4,202,000,000,000 tons of the amount contained in the Americas, or 51 percent of the total coal of the world. Listed according to coal reserves as estimated in 1913, the principal coal-producing countries of the world stand as follows:

TABLE 2.—*Coal reserves of the world, by countries*

	Net tons
United States, including Alaska	4, 231, 352, 000, 000
Canada	1, 360, 535, 000, 000
China	1, 097, 436, 000, 000
Germany	466, 665, 000, 000
Great Britain and Ireland	208, 922, 000, 000
Siberia	191, 667, 000, 000
Australia	182, 510, 000, 000
India	87, 083, 000, 000
U. S. S. R. in Europe	66, 255, 000, 000
Union of South Africa	61, 949, 000, 000
Austria	59, 387, 000, 000
Colombia	29, 763, 000, 000
Indo-China	22, 048, 000, 000
France	19, 382, 000, 000
Other countries	69, 369, 500, 000
Total	8, 154, 322, 500, 000

Since the publication of those estimates of reserves there has been a considerable reduction of the estimated reserves of the United States to the present figure of 3,180,765,230,000 net tons. See table 1.) As corrected figures are not available for the coal reserves of other countries, it is impossible to determine the effect of this revision on the relation of the reserves of the United States to those of the entire world.

Distribution of Coal in the United States

The areal distribution of coal in the United States is shown on the coal map (fig. 2). From that map it is apparent that large areas of coal lands are present in or near all parts of the country except the Pacific coast region.

On that map the coals have been divided into several ranks (anthracitic, including anthracite and semianthracite; low-volatile bituminous; medium- and high-volatile bituminous; subbituminous; and lignite). Those divisions have been made because coals of different ranks are adaptable to different uses.

In general, the coals west of Oklahoma, Kansas, and Iowa are of low rank. High quality coking coals are present in only a few areas in the Western States, the most important places being the Raton-Trinidad area of Colorado and New Mexico and the Sunnyside area of Utah.

From a study of the percentage distribution of the coal reserves (table 4) it is seen that the great volume of our coal is represented by the low-rank coals of the West, whereas the major part of our high-rank coals lies in the much smaller reserves of the East.

Explanation of the Estimates of Reserves

An estimate of the mineral resources of a region must be based on a combination of facts and assumptions. Consequently, the basis for any estimate must be known before that estimate can be properly evaluated or used intelligently. For that reason, the following statements are given.

The accompanying estimates of the coal resources of the United States are based primarily on the estimates prepared for the Geological Survey, United States Department of the Interior, in 1928 by M. R. Campbell. The estimates of original tonnage made by Campbell have been accepted without modification. The amounts of coal produced and the amounts lost in mining and marketing have been brought up to date as of January 1, 1937.

The data used by Campbell in computing the original tonnages of the various ranks of coal are given below.

Number and extent of coal fields.—The number and extent of the various coal fields of commercial interest in the United States have been well established by field work of the Geological Survey, United States Department of the Interior, and the various State geological surveys. Little information is available about some small coal areas, and estimates of their resources are little more than guesses. However, the total resources of such small, little-known areas constitute only a small percentage of the total for the entire country.

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[1] *The Coal Resources of the World:* An inquiry made on the initiative of the executive committee of the XII International Geological Congress, Canada, 1913, Morang & Co. (Ltd.), Toronto, Canada.

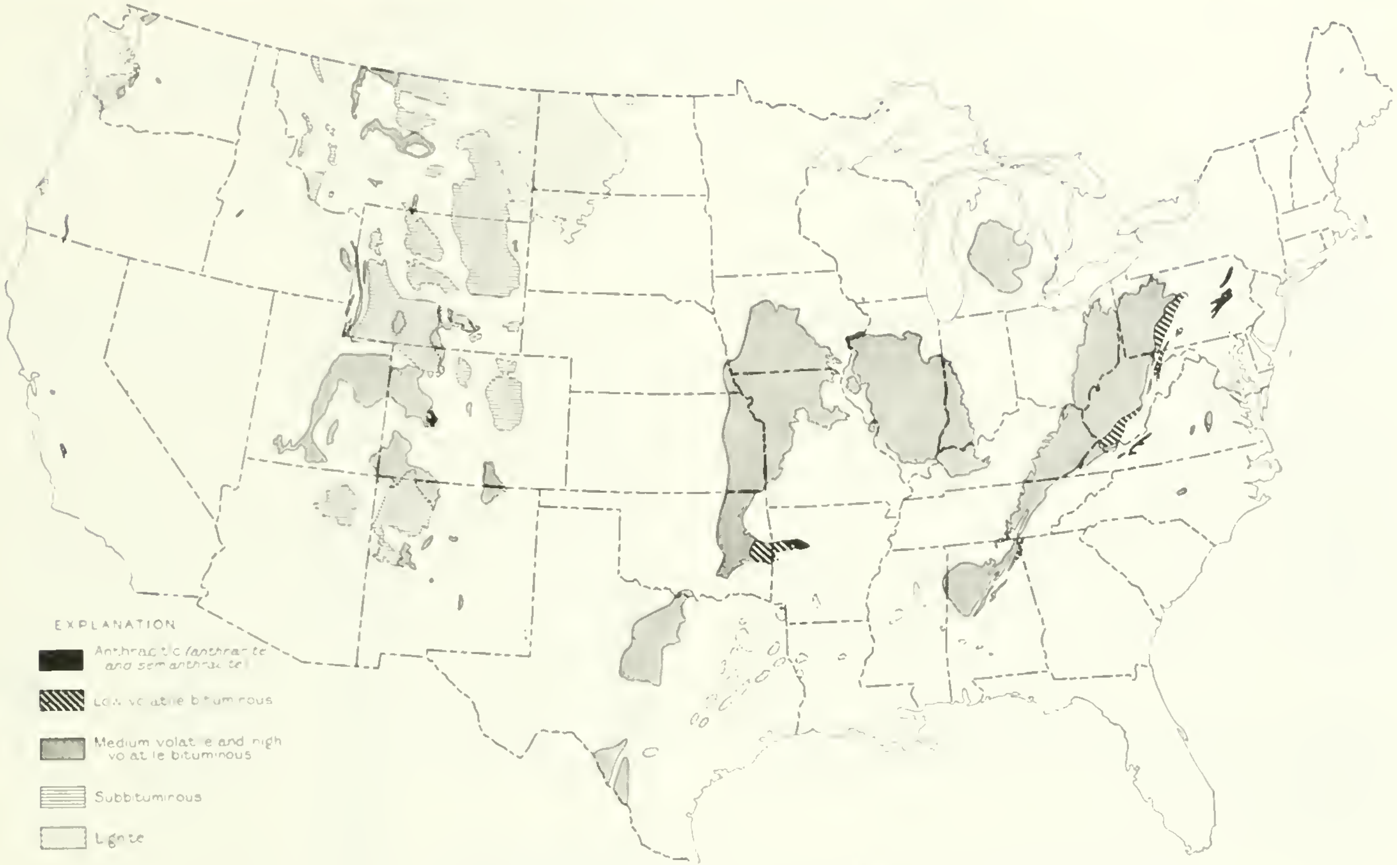
EXPLANATION
Anthracitic (anthracite and semianthracite)
Low volatile bituminous
Medium volatile and high volatile bituminous
Subbituminous
Lignite

FIGURE 2.—Coal Fields of the United States. Prepared by the Geological Survey, Department of the Interior.

TABLE 3.—*Coal resources of the United States*

[(A) the original tonnage of the various ranks of coal by States, (B) the amounts produced, (C) the estimated losses in mining and marketing, and (D) the estimated reserves of available coal at the end of 1936, all in net tons (2,000 pounds)]

State	Symbol	Anthracitic coal	Bituminous coal	Subbituminous coal	Lignite
Alabama	A		67, 570, 000, 000		
	B		615, 526, 287		
	C		327, 090, 668		
	D		66, 627, 383, 000		
Arizona, California, Idaho, and Oregon	A		697, 000, 000	1, 757, 000, 000	
	B		3, 186, 830	2, 462, 862	
	C		1, 693, 481	1, 308, 844	
	D		692, 120, 000	1, 753, 228, 000	
Arkansas	A	230, 000, 000	1, 396, 000, 000		90, 000, 000
	B	4, 770, 461	67, 201, 147		
	C	2, 535, 022	35, 710, 689		
	D	222, 695, 000	1, 293, 088, 000		
Colorado	A	100, 000, 000	213, 071, 000, 000	104, 175, 000, 000	
	B	5, 612, 778	296, 428, 300	81, 643, 060	
	C	2, 982, 630	157, 521, 998	43, 385, 122	
	D	91, 405, 000	212, 617, 050, 000	104, 049, 972, 000	
Georgia	A		933, 000, 000		
	B		10, 908, 240		
	C		5, 796, 638		
	D		916, 295, 000		
Illinois	A		201, 400, 000, 000		
	B		2, 354, 278, 599		
	C		1, 251, 063, 647		
	D		197, 794, 658, 000		
Indiana	A		53, 051, 000, 000		
	B		703, 325, 536		
	C		373, 747, 189		
	D		51, 973, 927, 000		

TABLE 3.—*Coal resources of the United States*—Continued

State	Symbol	Anthracitic coal	Bituminous coal	Subbituminous coal	Lignite
Iowa	A		29,160,000,000		
	B		305,101,700		
	C		162,131,043		
	D		28,692,767,000		
Kansas	A		30,000,000,000		
	B		226,171,028		
	C		120,187,284		
	D		29,653,642,000		
Kentucky	A		123,327,000,000		
	B		1,162,882,950		
	C		617,955,999		
	D		121,546,161,000		
Maryland	A		8,043,000,000		
	B		238,397,589		
	C		126,684,478		
	D		7,677,918,000		
Michigan	A		2,000,000,000		
	B		43,354,145		
	C		23,038,392		
	D		1,933,607,000		
Missouri	A		84,000,000,000		
	B		208,194,999		
	C		110,634,822		
	D		83,681,170,000		
Montana	A		2,655,000,000	62,985,000,000	315,474,000,000
	B		23,466,200	88,012,377	624,947
	C		12,469,938	46,769,777	332,096
	D		2,609,060,000	62,850,218,000	315,473,043,000
New Mexico	A	100,000	18,925,000,000	1,906,000,000	
	B	26,000	74,781,947	28,272,828	
	C	7,800	39,739,126	15,024,180	
	D	66,000	18,810,479,000	1,862,703,000	
North Carolina	A		68,000,000		
	B		1,217,664		
	C		647,066		
	D		66,135,000		
North Dakota	A				600,000,000,000
	B				35,572,335
	C				18,903,138
	D				599,945,525,000
Ohio	A		93,967,000,000		
	B		1,310,369,078		
	C		696,330,128		
	D		91,960,301,000		
Oklahoma	A		54,951,000,000		
	B		127,430,303		
	C		67,716,463		
	D		54,755,853,000		
Pennsylvania	A	21,000,000,000	112,148,000,000		
	B	4,186,065,258	5,777,184,470		
	C	2,224,475,078	3,069,995,827		
	D	14,589,460,000	103,300,820,000		
South Dakota	A				1,020,000,000
	B				242,840
	C				129,045
	D				1,019,628,000
Tennessee	A		25,665,000,000		
	B		244,984,195		
	C		130,184,601		
	D		25,289,831,000		
Texas	A		8,000,000,000		23,000,000,000
	B		10,398,360		46,767,470
	C		5,525,688		24,485,223
	D		7,984,076,000		22,928,747,000
Utah	A		88,184,000,000	5,156,000,000	
	B		135,691,000	2,344,636	
	C		72,106,197	1,245,939	
	D		87,976,203,000	5,152,409,000	
Virginia	A	500,000,000	21,149,000,000		
	B	7,198,430	328,080,210		
	C	3,825,245	174,341,823		
	D	488,976,000	20,646,578,000		
Washington	A	23,000,000	11,413,000,000	52,442,000,000	500,000
	B		106,340,894	16,768,210	
	C		56,509,551	8,910,626	
	D		11,250,150,000	52,416,321,000	

TABLE 3.—*Coal resources of the United States*—Continued

State	Symbol	Anthracitic coal	Bituminous coal	Subbituminous coal	Lignite
West Virginia	A		152, 544, 000, 000		
	B		3, 131, 681, 706		
	C		1, 664, 177, 252		
	D		147, 748, 138, 000		
Wyoming	A		30, 563, 000, 000	590, 160, 000, 000	
	B		164, 633, 104	105, 104, 486	
	C		87, 486, 031	55, 852, 523	
	D		30, 310, 881, 000	589, 999, 043, 000	
Estimated original tonnage		21, 853, 100, 000	1, 434, 880, 000, 000	818, 581, 000, 000	939, 584, 500, 000
Amount mined and wasted		6, 437, 498, 000	27, 071, 709, 000	497, 106, 000	127, 057, 000
Amount available at end of 1936		15, 415, 602, 000	1, 407, 808, 291, 000	818, 083, 894, 000	939, 457, 443, 000
Percentage of original tonnege still available		70. 54	98. 11	99. 93	99. 98

Number and thickness of coal beds.—In the better known fields of the East, the number and thickness of the coal beds have been fairly well determined by developed mines, by surface prospects, and by drill holes. In the West, the coal beds are not generally so well known because there are fewer mines and less drilling has been done for the purpose of testing the coals. Surface prospecting, however, has been carried on in almost every field, and this work, together with natural outcrops of coal and of the clinker produced from burned coal, has given data by which, for most fields, fairly good estimates can be made.

Weight of coal.—The weight of coal varies according to the rank of the coal, its moisture content, impurity, and the nature of its coal-forming ingredients. Campbell assumed the average specific gravity of coal to be 1.3 for coals in general, and his estimates of tonnages were made on that basis. As a cubic foot of water weighs 62.5 pounds, a cubic foot of coal with a specific gravity of 1.3 would weigh 62.5×1.3 or 81.25 pounds. On this basis, an acre of coal 1 foot thick would contain about 1,770 net tons, and a square mile of coal 1 foot thick would contain 1,132,560 net tons. The assumed specific gravity of 1.3 is lower than the average value suggested by some later determinations, and as a consequence, Campbell's estimates of original tonnages may be somewhat lower than they should be.

Minimum thickness of minable coal.—In commercial work, none but beds that are thick enough to be mined at the present time are considered, but in estimating the amount of ultimately available coal, it is necessary to include the thinnest beds that will be mined when all the thicker beds have been exhausted. The minimum thicknesses used by Campbell were 14 inches for bituminous and anthracitic coals, 2 feet for subbituminous coal, and 3 feet for lignite.

Maximum depth of mining.—It is recognized by all engineers that as soon as the coal beds near the surface are exhausted, deeper ones will be mined, but there is necessarily a limit in depth to profitable mining. The only evidence on this point is the depth to which coal mining is carried on today in foreign countries where coal is scarce. As mining in such countries has already reached a depth of more than 3,500 feet, it seems reasonable to assume that eventually all coal beds within 3,000 feet of the surface might be considered easily accessible and that beds at even greater depths might be worked at a profit. The estimates prepared by Campbell were limited to a depth of 3,000 feet.

There is comparatively little coal in the United States that lies at depths below 3,000 feet, and most of that coal is present in Western States that have large

TABLE 4.—*Percentage of reserves of the various ranks of coal by States*

	Percentage of reserves			
	Anthracitic coal	Bituminous coal	Subbituminous coal	Lignite
Alabama		4. 73		
Arizona, California, Idaho, and Oregon		.05	0. 21	
Arkansas	1. 44	.09		0. 01
Colorado	. 60	15. 10	12. 72	
Georgia		. 07		
Illinois		14. 05		
Indiana		3. 69		
Iowa		2. 04		
Kansas		2. 10		
Kentucky		8. 63		
Maryland		. 55		
Michigan		. 14		
Missouri		5. 94		
Montana		. 19	7. 68	33. 58
New Mexico	(1)	1. 34	. 23	
North Carolina		(1)		
North Dakota				63. 86
Ohio		6. 53		
Oklahoma		3. 89		
Pennsylvania	94. 64	7. 34		
South Dakota				. 11
Tennessee		1. 80		
Texas		. 57		2. 44
Utah		6. 25	. 63	
Virginia	3. 17	1. 47		
Washington	. 15	. 80	6. 41	(1)
West Virginia		10. 49		
Wyoming		2. 15	72. 12	

[1] Less than 0.01.

reserves of coal of the same rank as the deeply buried coal. The maximum depth of 3,000 feet assumed by Campbell therefore appears to be reasonable.

Records of production.—The production records used in preparing these estimates were taken from Campbell's estimates for the period prior to 1929, and from figures of the Bureau of Mines, United States Department of the Interior, for the period 1929–36, inclusive. In some States, such as Colorado and Washington, coal of two or more different ranks has been mined in some counties, and it has been necessary to estimate the proportionate amount of coal of each rank that has been mined in those counties.

Losses in mining.—An elaborate field investigation of wastes in the mining of bituminous coal was made by the United States Coal Commission and the Bureau of Mines in 1923.[2] The average amount of coal lost in mining was determined as 34.7 percent of the amount originally in the ground in the area of mining. Thus, 65.3 percent of the original coal tonnage is produced, and 34.7 percent is lost. The 34.7 percent lost is more than half (0.5314) of the 65.3 percent produced. Therefore, for each ton of coal produced, more than half a ton (0.5314) is lost.

In the preparation of these estimates of reserves, the losses in mining have been computed by multiplying the tons mined by 0.5314. The amount thus determined has been added to the amount produced and the resulting total deducted from the estimated original tonnage, in order to determine the estimated tonnages of reserves as of January 1, 1937.

Future mining losses.—Attention should be called to the fact that the estimate of available reserves given in table 3 makes no allowance for future loss in mining and marketing. Therefore, it is apparent that the "available reserves" are materially larger than the amount of coal that can be produced.

According to the data of the United States Coal Commission,[3] more than half of the coal lost in mining (19.4 of the total 34.7 percent) may be classified as due to avoidable loss. Therefore, it is apparent that improvements in mining and marketing practices can reduce the total coal losses. For that reason, no estimate of future coal losses has been made.

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[2] Rice, G. S., and Paul, J. W., "Amount and Nature of Losses in Mining Bituminous Coal in Eastern United States." *Report of the United States Coal Commission, 1923,* pt. 3, pp. 1841–76.

[3] Rice, G. S., and Paul, J. W., *op. cit.*, p. 1858.

CHAPTER 2.—PETROLEUM RESERVES

By H. D. Miser, G. B. Richardson, and C. H. Dane*

The United States depends on its petroleum reserves for an important part of its present and future power requirements (see fig. 3) and for continued national security. These reserves can be only imperfectly known. Petroleum is a liquid contained in the rocks deep below the surface in many small, widely scattered areas. (See fig. 4.) It is discovered by the driller who is aided in his search by the accumulated knowledge about oil and its occurrence. The more than 900,000 wells drilled for oil in this country have supplied data from which estimates of the reserves of this essential mineral fuel have been made from time to time by individuals, commercial organizations, and governmental agencies. A brief discussion of the estimates that have been made to the present time is given below; but, in order that their importance may be viewed in proper perspective, the discussion of the reserves is preceded by a brief outline of the magnitude of the petroleum industry itself and the volume of its output.

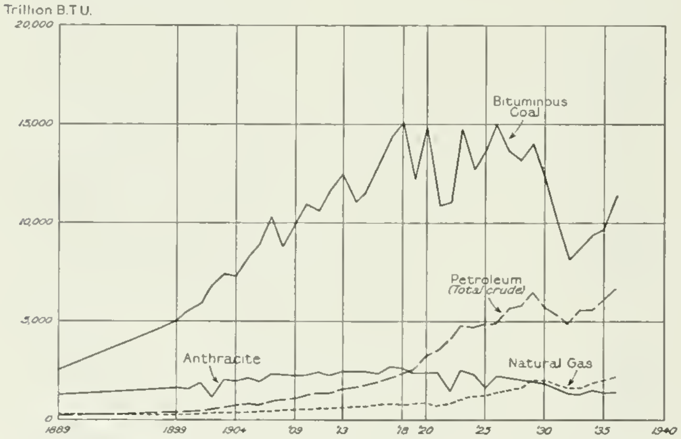

FIGURE 3.—Annual Supply of Energy from Mineral Fuels in the United States from 1889 to 1936. Compiled by the Geological Survey, Department of the Interior. Data from Bureau of Mines.

Growth of Petroleum Industry in United States

The petroleum industry in the United States is one of the Nation's most important industries. In it is invested $13,775,000,000. Although oil from shafts and natural seepages has been known for many thousands of years and was used to a slight extent for lighting and heating and for medicinal purposes as far back as the beginning of recorded history, the modern petroleum industry was born in 1859 with the discovery of oil in the Drake well in Pennsylvania.

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*Geological Survey, U. S. Department of the Interior.

The growth of the American petroleum industry, as revealed by statistics of output, has been phenomenal. This is especially true after the beginning of the present century. The first billion barrels of oil had been produced by 1900, 41 years after the first barrel was recovered from the Drake well, but during the next 37 years the volume of production was 19 times greater. The industry's seventy-ninth anniversary, 1938, has witnessed the production of the twenty billionth barrel of oil and will probably witness also the production of the twenty-first billionth barrel. (See fig. 5.) Twenty-two States (see fig. 4) have supplied the total output, amounting to 19,972,000,000 barrels through 1937. Among these States Texas stands first, having produced 5,127,000,000 barrels through 1937—a quarter of all the Nation's output of oil. California has produced 4,872,000,000 barrels, 24 percent, and Oklahoma 4,341,000,000 barrels, 21 percent. These three States together have contributed 72 percent of all the domestic output of oil. The total production of each of these States is greater than that of the U. S. S. R.—3,771,000,000 barrels through 1937—which ranks next to the United States in point of cumulative production.

Of the world's output of oil in 1937 (2,040,500,000 barrels), 63 percent (1,277,653,000 barrels) came from the United States. A similar proportion—60 percent—of the world's consumption of petroleum products and related fuels in 1937 was consumed in the United States. Briefly, this country produces and consumes three-fifths of the world's output of petroleum. This proportionately large volume of oil contributed by the United States is even more impressive when a comparison of the world's known reserves reveals that foreign countries possess about 52 percent of the reserves.[1]

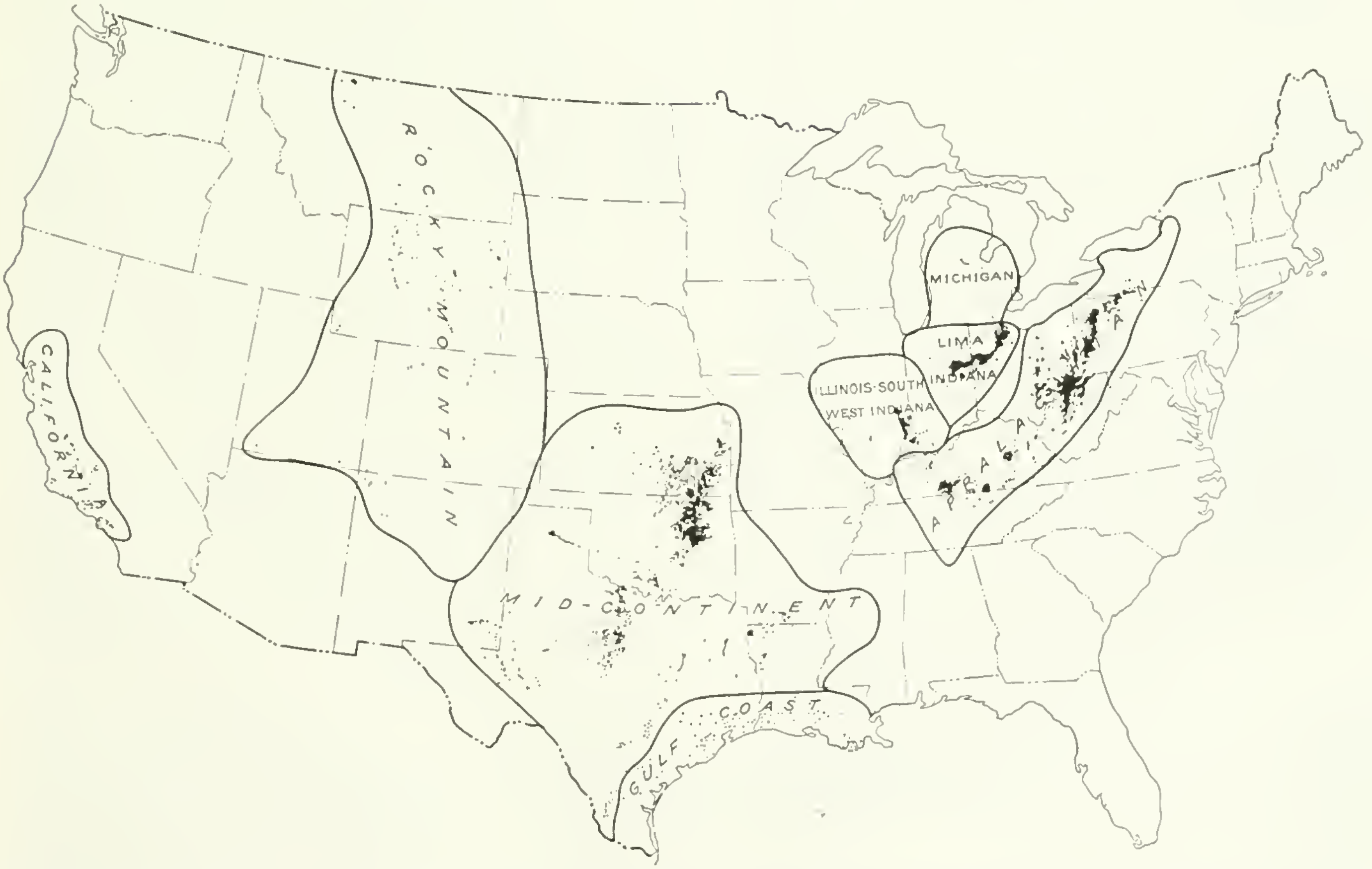

FIGURE 4.—Map of the United States Showing Oil Fields and Producing Regions. Prepared by the Geological Survey, Department of the Interior. The relative contribution of the several producing regions is given by the following percentages of the national production in 1937: Mid-Continent, 60.6; California, 18.6; Gulf Coast, 13.9; Appalachian, 2.9; Rocky Mountain, 2.1; Michigan, 1.2; Illinois-Southwest Indiana, 0.6; Lima-Indiana, 0.1.

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[1] Garfias, V. R., and Whetsel, R. V., "Proven Oil Reserves," *Am. Inst. Min. Met. Eng. Trans.*, vol. 118, 1936, p. 214. Their estimates of proven oil reserves in millions of barrels, as of January 1, 1936, are as follows:

United States	10,575
Russia	2,830
Iraq	2,475
Iran	2,150
Venezuela	1,350
Rumania	633
Netherlands East Indies	450
Mexico	420
Colombia	275
Peru	138
British India	111
Argentina	92
Trinidad	91
Others	375
Total	21,965

The Petroleum Supply of the United States

The working supply of the petroleum industry consists of the stocks of crude petroleum held above ground in tank farms, at refineries. in transit, or by producers at wells. These stocks are being constantly consumed and are constantly replenished from current production. They constitute only a few months' supply. Total stocks of crude petroleum in the United States on December 31, 1937, according to the preliminary figures of the Bureau of Mines, amounted to 306,084,000 barrels. The imports of crude petroleum and refined products are large in total amount (nearly 60 million barrels in 1937), but they supply only 5 percent of the domestic consumption.

Aside from these stocks and imports, the supply of petroleum includes the amounts recoverable by present methods of production from known fields plus the intangible and unproved reserves of unknown fields to be discovered in the future.

Of the total supply of oil in the ground, only the volume already discovered with the drill may be regarded as proved or "known." The known supply is increased as new fields and deeper oil-bearing zones are discovered, but each year's output reduces by that amount the total supply.

Estimates of Petroleum Reserves

The first estimate of petroleum reserves in the United States was prepared in 1909, when conservation of the Nation's mineral resources, including petroleum, was receiving the serious consideration of President Theodore Roosevelt. At that time, the motor vehicle and petroleum industries, although inconsequential as compared with the present, were growing fast; in 1909 the two-billionth barrel of oil was brought to the surface, and the registration of motor vehicles in the United

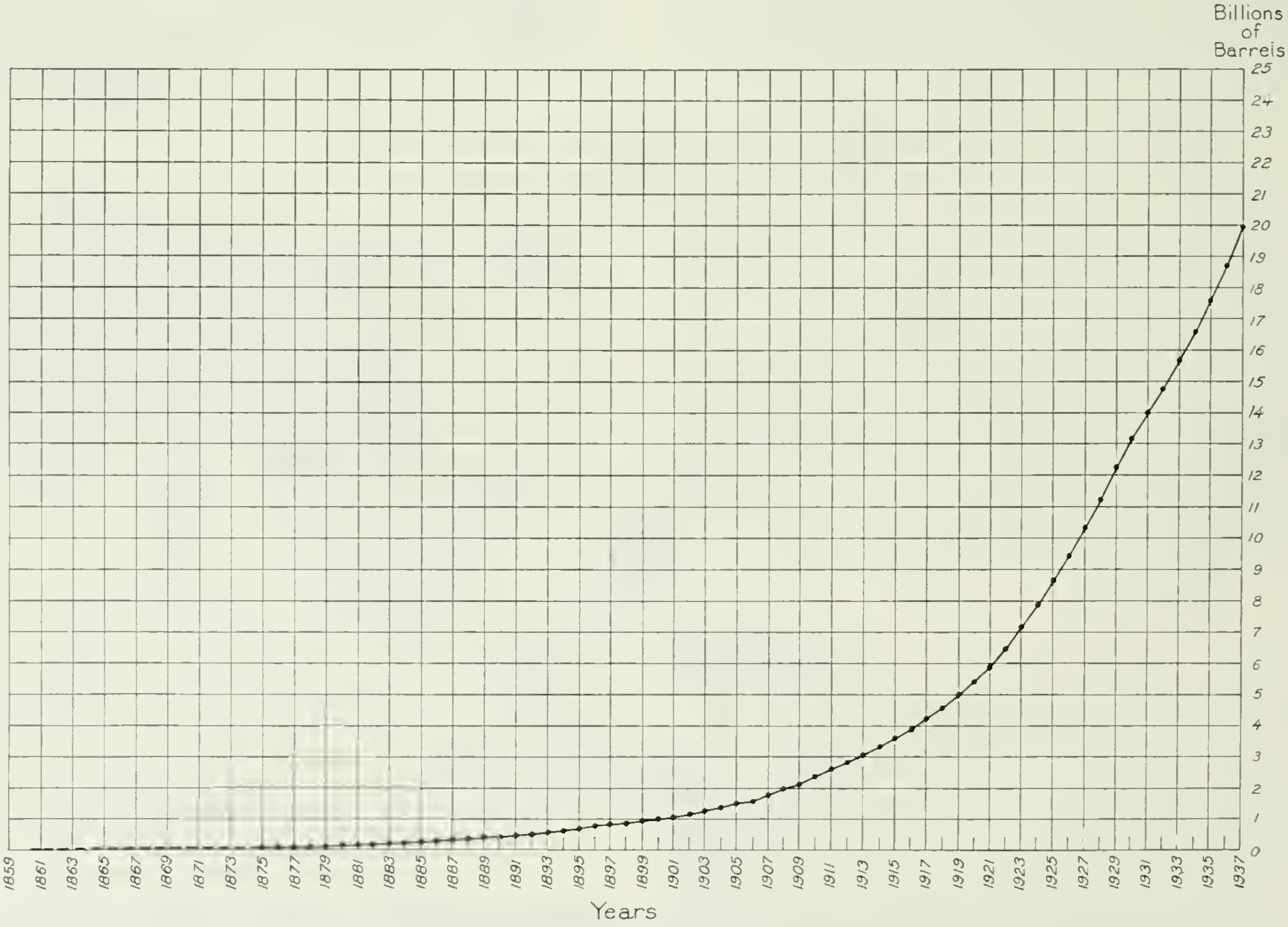

FIGURE 5.—Curve Showing Cumulative Production of Crude Petroleum in the United States. Compiled by the Geological Survey, Department of the Interior, from statistics provided by Bureau of Mines.

States reached 312,000. According to David T. Day, the author of this first estimate, the total petroleum yield of the United States might be as low as 10,000,000,000 barrels or as high as 24,500,000,000 barrels.[2]

A number of estimates of the total petroleum resources of the United States were prepared between 1909 and 1921. During this period, however, it gradually became evident that the unproved reserves in unknown fields awaiting future discovery could not be estimated with any degree of accuracy, whereas the quantity of oil in the proved reserves, recoverable by then current methods of production, could be estimated with reasonable accuracy on the basis of the past production of depleted fields. The first estimate in which the proved reserves were separated from estimates of undiscovered fields was made in 1921 by the Geological Survey with the cooperation of the American Association of Petroleum Geologists. In this estimate, 5 billion barrels were classified as oil "in sight" on January 1, 1922, and 4 billion barrels additional as "prospective and possible" and recoverable by then current methods of production.[3] This and a number of detailed estimates that have been prepared since 1921 are given in table 5 and are shown graphically for the years 1922 to 1938 in figure 6.

In 1925 the first of a series of estimates prepared by the American Petroleum Institute listed future production "from existing wells and from acreage these wells prove to be oil bearing, by present methods of flowing and pumping."[4] This estimate reported reserves, as of 1925, to be 5,321,427,000 barrels.

In September 1926 the Federal Oil Conservation Board stated that "From the most recent estimates, it would appear that the reserves of oil available by flowing and pumping wells from present producing and proven fields amount to about 4,500,000,000 barrels."[5]

In its fifth report, in October 1932, the Federal Oil Conservation Board stated: "Reserves made known by later discoveries have raised the current classification of known reserves to 10 billion barrels."[6]

In 1934 Hale B. Soyster, of the Geological Survey, prepared an estimate of reserves of oil for the special subcommittee on petroleum investigation of the Committee on Interstate and Foreign Commerce of the House of Representatives, Seventy-third Congress.[7] The reserves of oil from known fields recoverable by current methods, as of December 31, 1933, were estimated at 13,360,000,000 barrels.

The American Petroleum Institute, through its committee on petroleum reserves, has prepared reports on the proved petroleum reserves of the United States as of January 1, 1935, 1937, and 1938 and, in the light of later developments, revised the estimates for 1935 and 1937.[8] The committee in April 1938 reported that the "proven reserves" of the United States were 15,507,268,000 barrels on January 1, 1938. "The estimate made no allowance for possible reserves in untested areas * * * representing only the amount of crude oil which may be extracted by present known methods from fields now completely developed or drilled or sufficiently drilled and explored to permit of reasonably accurate calculations."

The individual estimates that have been mentioned, as well as many others, differ somewhat, but they all possess a similar order of magnitude and indicate that the proved reserves since 1930 amounted to 10 billion barrels or more. The distribution of the reserves by States is shown on figure 7.

The proved reserves in the ground, like the stocks of petroleum held above ground, are constantly changing in quantity. They are depleted by the output of producing wells and increased by the discovery of new fields and deeper pools. During the period 1922 to 1938, for which figures of proved reserves are available, many large fields were discovered, so that, notwithstanding the consequent greatly augmented production, the proved reserves have increased.

On the basis of the 5-billion-barrel estimate of oil "in sight" in 1922 and the 15.8-billion-barrel estimate of proved reserves in 1937 (see table 5 and fig. 6), the increase in the proved category during this 15-year period has been 10.8 billion barrels. Although the increase was not uniformly spread over the period, it is equivalent to about 720 million barrels for each year. The domestic production during the same period was 12,792 million barrels, which is equivalent to 853 million barrels for each year.

Until the estimate of the American Petroleum Institute of January 1, 1938, is revised as was the first estimate of 1937, the revised estimate of January 1937 and the present estimate of January 1938 are not strictly comparable.

(Continued on p. 292)

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[2] Day, D. T., *The Petroleum Resources of the United States*, U. S. Geol. Survey Bull. 394, 1909, p. 35.

[3] "The Oil Supply of the United States," *Am. Assoc. Petroleum Geol. Bull.*, vol. 6, 1922, no. 1, pp. 42–46.

[4] *American Petroleum Supply and Demand:* A report to the board of directors of the American Petroleum Institute by a committee of eleven members of the board, 1925, pp. 7, 58–59.

[5] *Report of the Federal Oil Conservation Board to the President of the United States*, 1926, pt. 1, p. 8.

[6] *Report V of the Federal Oil Conservation Board to the President of the United States*, 1932, p. 7.

[7] *Petroleum Investigation*, H. Res. 441, pt. 2, 1934, pp. 1071–1081.

[8] *Am. Petroleum Inst. Quart.*, vol. 7, April 1937, no. 2, p. 5, and vol. 8, April 1938, no. 2, pp. 12 and 13.

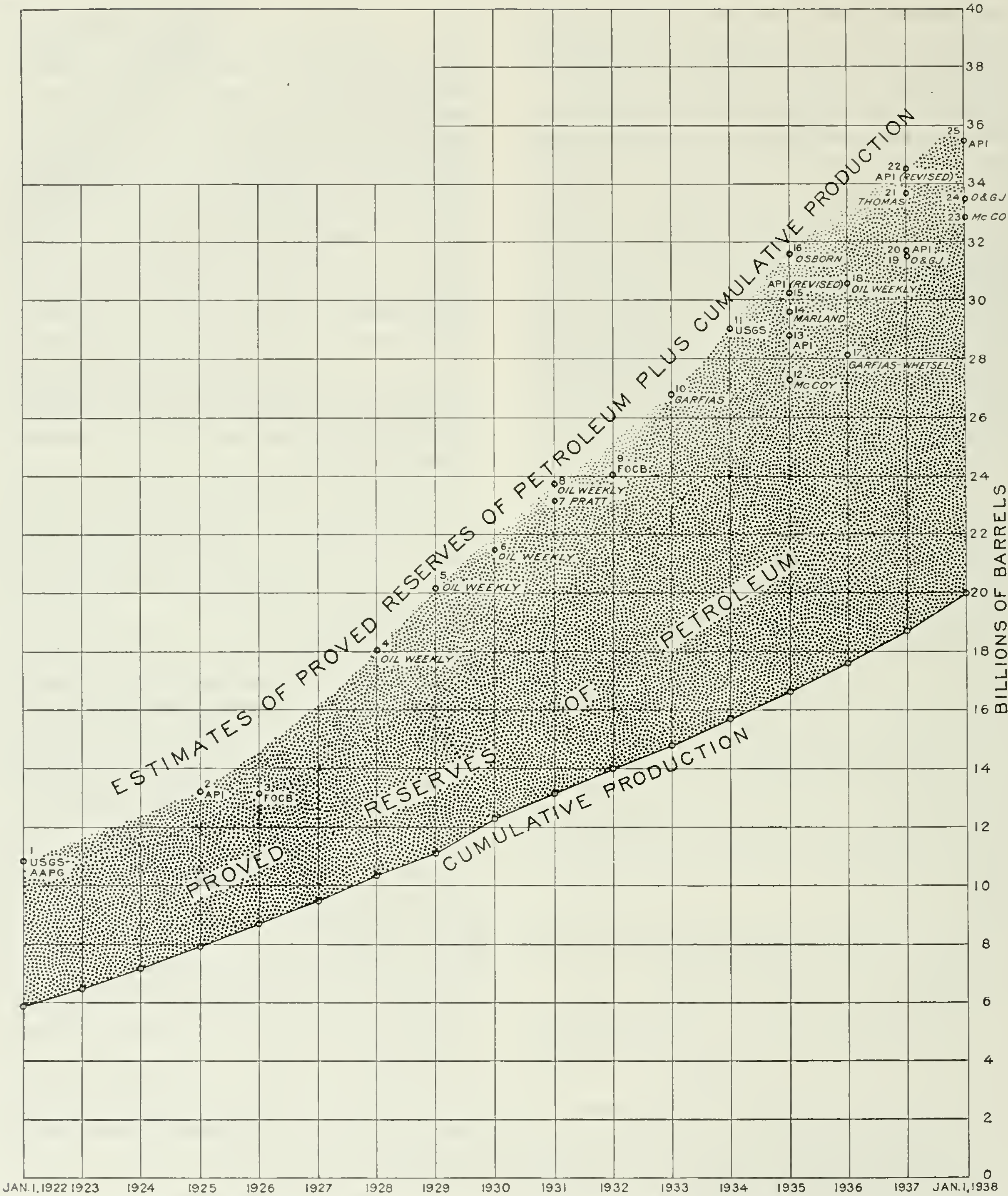

FIGURE 6.—Production and Proved Reserves of Petroleum, 1922–38. Prepared by the Geological Survey, Department of the Interior. Numbers correspond to those on opposite page; cumulative production as of January 1 of each year; estimates of proved reserves as of same date except as noted on opposite page.

ESTIMATES OF PETROLEUM RESERVES INDICATED BY LIKE NUMBERS ON FIGURE 6

1. 5,000,000,000 barrels. Estimate by joint committee representing the American Association of Petroleum Geologists and the Geological Survey in "The Oil Supply of the United States," *American Association Petroleum Geologists Bulletin*, volume 6, 1922, No. 1, pages 42–46.

2. 5,321,427,000 barrels as of 1925. A report to the board of directors of the American Petroleum Institute by a committee of eleven members of the board in *American Petroleum Supply and Demand*, 1925.

3. 4,500,000,000 barrels, as of September 6, 1926. *Report of the Federal Oil Conservation Board to the President of the United States*, 1926, part 1, page 8.

4. 7,704,000,000 barrels. H. J. Struth, "Who Said There Is Too Much Oil in Sight, Anyway?" *Oil Weekly*, volume 65, No. 5, pages 16–18, April 18, 1932.

5. 9,071,000,000 barrels. H. J. Struth, *idem*.

6. 9,199,000,000 barrels. H. J. Struth, *idem*.

7. 10,000,000,000 barrels. Wallace E. Pratt, "Industry Must Drill 20,000 Wells Yearly," *Oil and Gas Jour.*, volume 30, No. 9, pages 19 and 102–103, July 16, 1931.

8. 10,578,000,000 barrels. H. J. Struth, *op. cit.*, pages 16–18.

9. 10,000,000,000 barrels, as of October 1932. *Report V of the Federal Oil Conservation Board to the President of the United States*, 1932, pages 7 and 41.

10. 12,000,000,000 barrels. Valentin R. Garfias, "An Estimate of the World's Proven Oil Reserves," *Am. Inst. Min. Met. Eng. Trans.*, volume 103, 1933, pages 352–354.

11. 13,360,000,000 barrels. Hale B. Soyster, estimates of petroleum reserves, in "Geology and Occurrence of Petroleum in the United States" by the Geological Survey, *Petroleum Investigation:* hearings before subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, Seventy-third Congress, 1934, on House Resolution 441, part 2, pages 1071–1081.

12. 10,700,000,000 barrels. Statement of Alex W. McCoy, *Petroleum Investigation:* hearings before subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, Seventy-third Congress, 1934, on House Resolution 441, part 3, pages 1454–1458.

13. 12,177,000,000 barrels. Estimate by a special committee of the American Petroleum Institute, in "Petroleum Production and Supply," *American Association Petroleum Geologists Bulletin*, volume 20, January 1936, No. 1, pages 1–14.

14. 13,000,000,000 barrels, as of November 12, 1934. Statement of E. W. Marland, *Petroleum Investigation;* hearings before subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, Seventy-third Congress, 1934, on House Resolution 441, part 3, pages 1439–1445.

15. 13,632,000,000 barrels. Estimate by American Petroleum Institute committee on petroleum reserves, in "Nation's Proven Oil Reserves Placed at 13 Billion Barrels": *American Petroleum Institute Quarterly*, April 1937, volume 7, No. 2, page 5.

16. 15,000,000,000 barrels. Statement of Campbell Osborn, *Petroleum Investigation;* hearings before subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, Seventy-third Congress, 1934, on House Resolution 441, part 3, pages 1458–1463.

17. 10,575,000,000 barrels. V. R. Garfias and R. V. Whetsel, "Proven Oil Reserves," *Am. Inst. Min. Met. Eng. Trans.*, volume 118, 1936, pages 211–214.

18. 12,992,000,000 barrels. Warren L. Baker, "United States Crude Reserves Enlarged During 1935," *Oil Weekly*, volume 80, February 10, 1936, No. 9, pages 19–22.

19. 12,904,946,000 barrels. L. G. E. Bignell, *Oil and Gas Journal*, volume 36, January 27, 1938, No. 37, pages 38–39.

20. 13,063,000,000 barrels. Estimate by American Petroleum Institute Committee on Petroleum Reserves, in "Nation's Proven Oil Reserves Placed at 13 Billion Barrels," *American Petroleum Institute Quarterly*, volume 7, April 1937, No. 2, page 5.

21. 15,000,000,000 barrels. J. Elmer Thomas, "Proved Oil Reserves in United States of America," *American Association Petroleum Geologists Bulletin*, volume 21, 1937, No. 8, pages 1088–1091.

22. 15,856,190,000. "Institute Committee Estimates Nation's Proven Petroleum Reserves at New High," *American Petroleum Institute Quarterly*, volume 8, April 1938, No. 2, pages 12–13.

23. 12,909,000,000 barrels. Estimate by Alex W. McCoy, *Oil Weekly*, volume 88, January 31, 1938, No. 8, pages 10–11.

24. 13,489,457,000 barrels. L. G. E. Bignell, *Oil and Gas Journal*, volume 36, January 27, 1938, No. 37, pages 38–39.

25. 15,507,268,00 barrels. "Institute Committee Estimates Nation's Proven Petroleum Reserves at New High," *American Petroleum Institute Quarterly*, volume 8, April 1938, No. 2, pages 12–13.

In a report of the United States Department of the Interior Petroleum Administrative Board on the *Cost of Producing Crude Petroleum*, issued in December 1935, the proved reserves of crude petroleum on December 31, 1933, were estimated to have been 10,638,000,000 barrels, and on December 31, 1934, were estimated to have been 10,763,000,000 barrels. These estimates are stated not to include additional recovery from Pennsylvania obtainable by wider application of waterflooding methods.

Future Petroleum Supply

The continued discovery of new fields and deeper oil-bearing zones is required to meet future demands, just as it has been since the beginning of the industry in the United States. The present estimate of January 1938 (15,507 million barrels) is equivalent to a 12-years' supply at the rate of production in 1937 (1,277 million barrels). Such a volume of oil cannot, however, be extracted in this length of time from the present fields because of the normally declining rate of production that takes place from year to year.

The survival of the petroleum industry, like that of most other mineral industries, depends on the continued discovery of new sources of supply. The extent to which new sources of supply are discovered and developed depends upon the payment of such prices by the consumer as will permit the industry to carry the heavy and increasing expense of new exploration and still maintain profits.

Much oil remains to be discovered in new fields and in deeper pools. These will be found in areas indicated as "possible" on the accompanying map of the United States. (See fig. 8.) The exact location of these fields and the quantity of petroleum they will yield are not known; they will not be known in advance of drilling. Nevertheless, their number, whatever it may be, is definitely limited, and each newly found field leaves one less to be discovered.

Oil discovery has maintained, up to the present, a stock of reserves equivalent to 10 or more years' supply. The course of prospecting and development the past few years leads some observers to suggest that the limits of annual production have been nearly attained; this may be true, but a conclusive demonstration of it is not at hand. It will not be established that a shortage in production to meet annual requirements is imminent until future estimates of proved reserves decrease for a period of years of sufficient length to assure the elimination of temporary influences, such as lean years of discovery, and the addition of enormously large fields like East Texas.

The answer to the question "When will the day of petroleum shortage in the United States be reached?" lies not alone in the supply of oil remaining in the ground. It rests also with the geologist to continue to aid in the increasingly difficult problem of discovery;

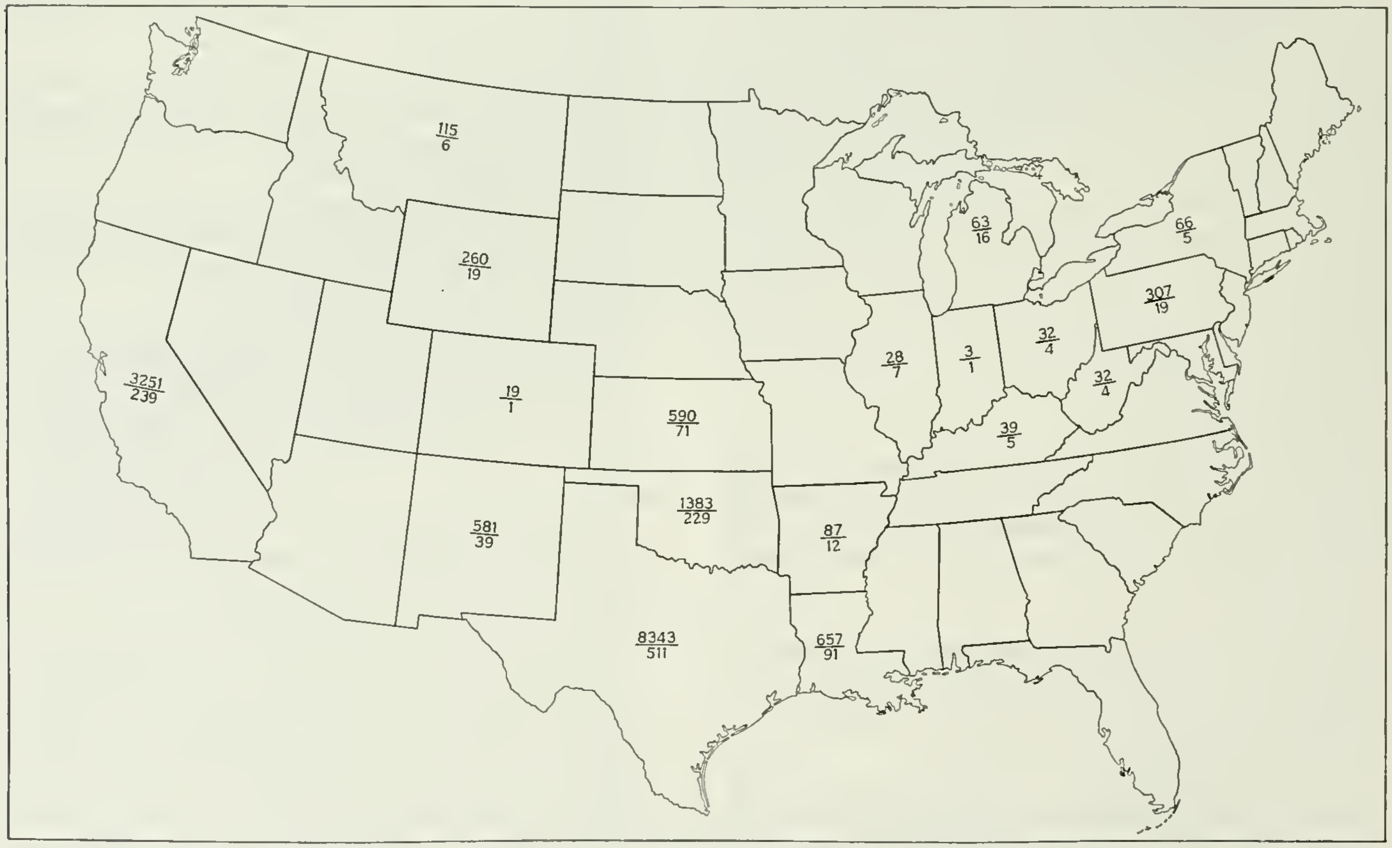

FIGURE 7.—Reserves of Petroleum in Millions of Barrels as Allocated to States in the Estimate of January 1937 of the American Petroleum Institute. Prepared by the Geological Survey, Department of the Interior. The lower figure in each State is the production in 1937 according to preliminary figures of the Bureau of Mines. Tennessee, Missouri, and Utah also contributed small amounts to the production in 1937, but the reserves of these States were not included in the estimate. All figures are given to the nearest million barrels.

with the engineer to continue to improve drilling technique and to increase recoveries; and with the chemist to continue improvements in refining practice. In part, it rests on the price that the public can pay in the future for oil products, and that, in turn, depends in part on increased efficiency in use. Man through necessity will recover more and more of the energy available in petroleum and in the related natural fuels—coal and natural gas. Continued and increasing cooperation will also promote conservation and efficiency in discovery, development, and production.

The future undoubtedly will see continued advances in science and technology affecting the discovery, recovery, refining, and utilization of petroleum. Thus far, these advances have enabled us to keep supplies ahead of needs; but they afford us no assurance that, as demand grows, the same record can be maintained.

In this connection, it is of interest to call attention to some of the concrete accomplishments of recent years. In the 15-year period from 1922 to the end of 1936, the geologist and the petroleum engineer have aided the driller in the addition of 10.8 billion barrels to our petroleum reserves, despite the production of 12.8 billion barrels during that period. From 1920 to the end of 1936 the chemist, by the introduction and improvement of cracking processes, has conserved 8.5 billion barrels of crude oil.[9] The petroleum engineer is meeting energetically the challenge to recover the 65 to 85 percent of oil remaining in the ground after a field no longer yields oil by the older methods of production. Each year witnesses the improvement and extension of recovery methods, such as acid treatment and repressuring by the introduction of gas, air, and water into the oil-bearing zones. The increased adoption and refinement of such methods in areas where geologic and other conditions permit their use will lead to the recovery in places of 50 percent or more of the total oil content of the producing zones.

Moreover, when a shortage of domestic crude petroleum arrives and when a consequent rise in prices of petroleum products occurs, substitutes—oil products from coal and possibly from oil shale—will be drawn upon just as they are now drawn upon to some extent in some countries that are supplied with little or no oil resources.

The volume of the coal resources of the United States is such that they may be depended upon to pro-

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[9] Van Covern, Fred, "Status and Outlook of Petroleum Supply, Demand, and Stocks," *Am. Petroleum Inst. Quart.*, vol. 7, April 1937, no. 2, p. 9.

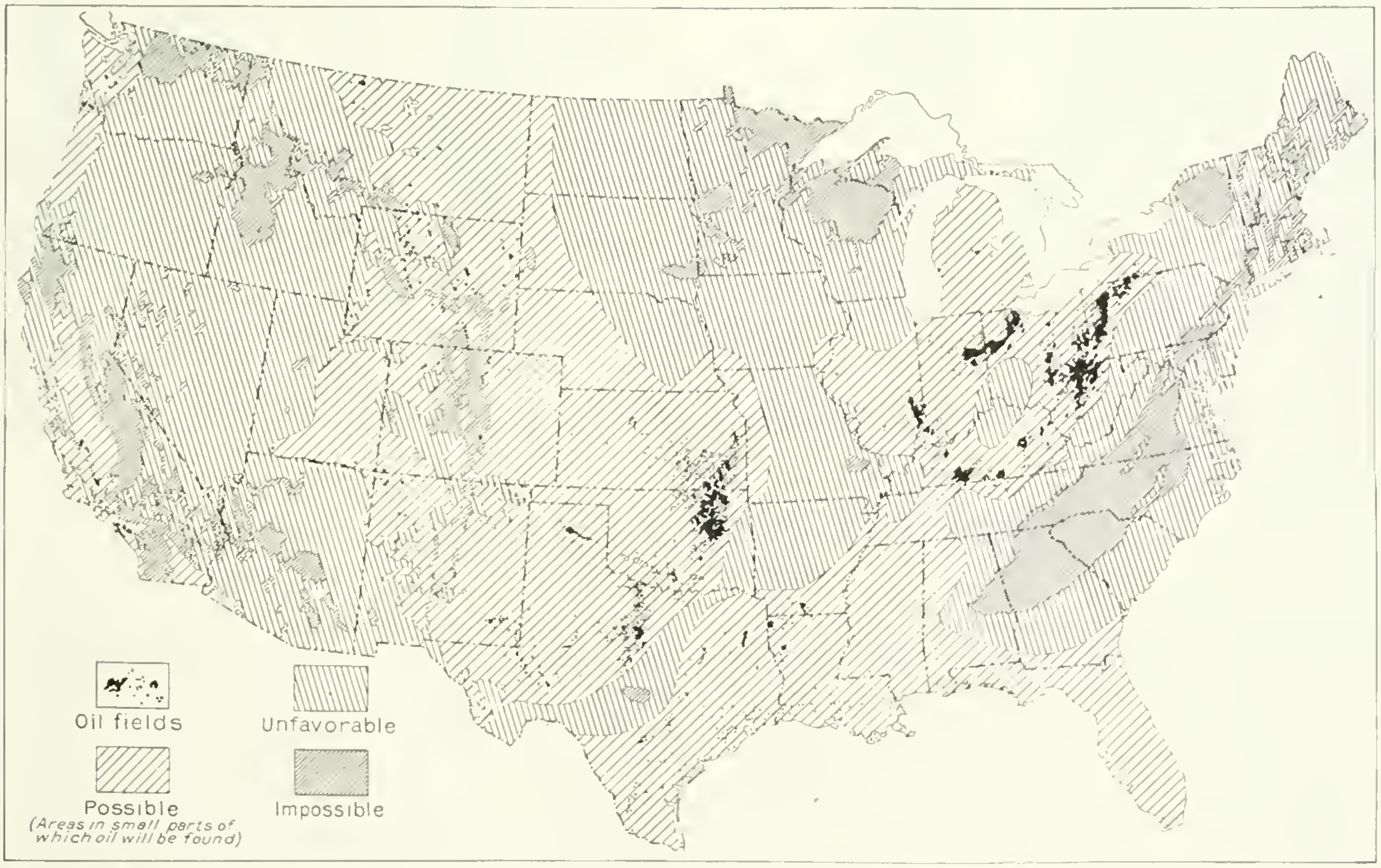

FIGURE 8.—Map of the United States Showing Oil Fields and Unproductive Areas Classified with Respect to Their Relative Likelihood of Yielding Commercial Quantities of Oil. Prepared by Geological Survey.

vide an adequate supply of motor fuel for many centuries after a shortage in crude petroleum arrives. The character, extent, and reserves of the Nation's coal are described in an accompanying chapter, prepared by T. A. Hendricks, of the Geological Survey, United States Department of the Interior.

It has been estimated that if, and when, the price permits, approximately 92,000,000,000 barrels of oil is recoverable from oil shale deposits of the United States.[10] Of this estimated quantity the source of approximately 75,000,000,000 barrels lies in oil shales of Tertiary age that crop out chiefly in northwestern Colorado and northeastern Utah and subordinately in Wyoming and Nevada. Small amounts of oil shale known or reported in California, Montana, and Oregon were not included in the estimate. The estimated total quantity includes also approximately 17,000,000,000 barrels believed to be recoverable from black shales of Devonian age in Indiana and Kentucky that are accessible to mining by open-cut methods. Smaller amounts of minable shale of this type are doubtless available in other States.

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[10] Winchester, D. E., "The Oil Possibilities of the Oil Shales of the United States," *Report II of the Federal Oil Conservation Board to the President of the United States,* 1928, pp. 13–14.

TABLE 5.—*Estimates of proved reserves of petroleum by governmental agencies, American Association of Petroleum Geologists, and the American Petroleum Institute. Other estimates are shown on fig. 6*

	1922 (Jan. 1) U. S. Geological Survey-American Association of Petroleum Geologists, *American Association of Petroleum Geologists, Bull.* vol. 6, No. 1, pp. 42–46, 1922	1925 Committee of Eleven, American Petroleum Institute, *American Petroleum Supply and Demand,* pp. 58–59, 1925	1926 *Report of Federal Oil Conservation Board to President of United States,* pt. 1, p. 8, 1926	1932 *Report V of Federal Oil Conservation Board to President of United States,* pp. 7, 41, 1932	1934 (Jan. 1) Hale B. Soyster in U. S. Geological Survey, "Geology and Occurrence of Petroleum in United States," *Petroleum Investigation;* House of Representatives, 73d Cong. hearings on H. Res. 441, pt. 2, pp. 1071–1081, 1934	1935 (Jan. 1) (revised estimate) American Petroleum Institute Committee on Petroleum Reserves, *American Petroleum Institute Quarterly,* v ol, 7, No. 2, p. 5, April 1937	1937 (January) (revised estimate) American Petroleum Institute Committee on Petroleum Reserves, *American Petroleum Institute Quarterly,* vol. 8, No . 2, pp. 12-13, April 1938	1938 (Jan. 1) American Petroleum Institute Committee on Petroleum Reserves, *American Petroleum Institute Quarterly,* vol. 8, No. 2, pp. 12–13, April 1938
Arkansas		122, 150, 000			29, 500, 000	103, 000, 000	87, 493, 000	192, 101, 000
California		2, 139, 987, 000			5, 422, 500, 000	3, 261, 000, 000	3, 250, 726, 000	3, 063, 142, 000
Colorado		48, 462, 000			8, 500, 000	16, 000, 000	18, 622, 000	19, 125, 000
Illinois		112, 000, 000			34, 000, 000	37, 000, 000	28, 210, 000	40, 884, 000
Indiana		11, 500, 000			5, 000, 000	5, 000, 000	3, 441, 000	2, 622, 000
Kansas		314, 501, 000			194, 000, 000	390, 000, 000	590, 000, 000	601, 317, 000
Kentucky		78, 974, 000			30, 000, 000	50, 000, 000	38, 846, 000	38, 366, 000
Louisiana		133, 870, 000			136, 000, 000	513, 000, 000	656, 844, 000	713, 434, 000
Michigan					17, 000, 000	64, 000, 000	62, 614, 000	49, 181, 000
Montana		9, 900, 000			57, 000, 000	102, 000, 000	115, 210, 000	109, 378, 000
New Mexico		12, 900, 000			92, 500, 000	451, 000, 000	581, 025, 000	546, 587, 000
New York		16, 000, 000			45, 000, 000	75, 000, 000	66, 000, 000	60, 535, 000
Ohio		120, 000, 000			34, 000, 000	40, 000, 000	32, 000, 000	28, 456, 000
Oklahoma		1, 039, 093, 000			844, 500, 000	1, 235, 000, 000	1, 383, 464, 000	1, 212, 252, 000
Pennsylvania		86, 000, 000			252, 500, 000	340, 000, 000	307, 000, 000	287, 886, 000
Texas		732, 040, 000			5, 884, 000, 000	6, 643, 000, 000	8, 343, 114, 000	8, 247, 928, 000
Utah		500, 000						
West Virginia		48, 000, 000			27, 500, 000	40, 000, 000	31, 976, 000	28, 152, 000
Wyoming		295, 550, 000			245, 000, 000	267, 000, 000	259, 605, 000	265, 922, 000
Others					1, 500, 000			
Total	5, 000, 000, 000	5, 321, 427, 000	4, 500, 000, 000	10, 000, 000, 000	13, 360, 000, 000	13, 632, 000, 000	15, 856, 190, 000	15, 507, 268, 000

CHAPTER 3.—NATURAL GAS RESERVES

By Ralph W. Richards*

Commercial production of natural gas in the United States started in Fredonia, N. Y., about 1820, when gas from a shallow well was supplied through a lead pipe to 30 domestic burners. In 1872 a wooden pipe line was constructed from West Bloomfield, N. Y., to Rochester, a distance of 25 miles. Now 85,000 miles of trunk lines are required to transport the gas from fields in 24 States to consuming centers in 35 States. Consumption of gas is rapidly mounting toward 3 trillion (thousand billion) cubic feet per year. The rapid growth in the use of this convenient and efficient source of heat and energy has accentuated the importance of the future supply and the availability of reserves of natural gas.

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*Geological Survey, U. S. Department of the Interior.

The cumulative marketed production of gas since 1906 amounts to 37.81 trillion cubic feet. (See fig. 9.) No reliable figures on the total production of natural gas are available, the total amount of gas wasted, utilized in field operations, and lost in transmission being unknown.

About half of the gas reserves of the United States (fig. 10) have practically the same geographic distribution as the oil reserves. (See chapter on petroleum reserves.) This is so because approximately half of the natural gas is produced with oil; the gas is, in fact, the source of energy which brings the oil to the surface. For many years between 1,500 to 2,000 cubic feet of natural gas to the barrel of oil has been marketed, and the tendency is that this ratio will increase in the future. Since our proved oil reserves are of the order of 15 billion barrels, we are assured of a minimum reserve of 22.5 to 30 trillion cubic feet of natural gas. Gas, however, is found in many areas that do not produce oil, and also greater quantities of gas are now being found with the oil that is discovered and produced from progressively greater depths.

During the first 50 years of the natural-gas industry, utilization was confined to areas not more than 100 to 250 miles distant from the fields; but the discovery of extensive reserves of gas in the midcontinent area (notably in Louisiana in 1916 and in the Texas Panhandle in 1918), and in California in 1926 and 1928, was followed by the financing and building of thousand-mile pipe lines that entered a Nation-wide market. The construction of such lines was, in part, made possible by the expansion of facilities for the production of seamless and welded pipe lines of large diameter (18 to 26 inches), capable of transporting large volumes of gas at high pressure with almost negligible losses.

During this period of expansion of the industry, estimates of the quantities of gas contained in the new fields were required as an assurance that the supplies provided an adequate basis for financing. Also, because of the consequent increased national importance

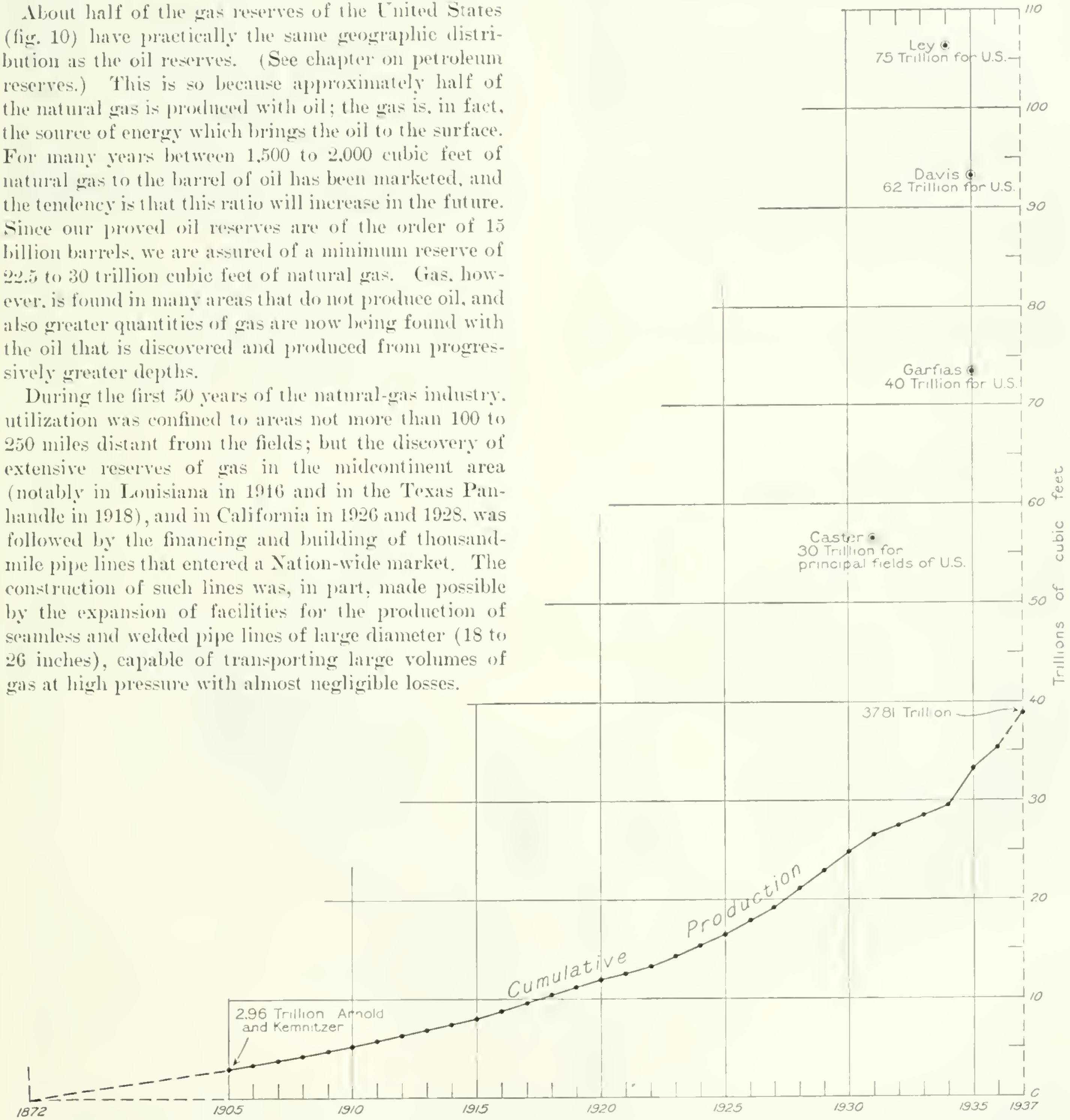

FIGURE 9.—Marketed Production of Natural Gas from 1905 to 1937 and Estimates of Reserves. Prepared by the Geological Survey, Department of the Interior. The estimates are added to the cumulative production curve.

of natural gas, inventories of the gas resources of the United States, in terms of volume and years supply, were attempted.

Huntley and Mason [1] in 1930 estimated the reserves of gas produced with oil in the United States east of the Rockies at a minimum of 49.5 trillion cubic feet. They based this estimate upon an assumed continuance of the past 15-year ratio of 2,250 cubic feet of gas to the barrel of oil. They did not attempt to estimate the gas reserves of the Pacific coast, but they suggested that the minimum oil reserves of that area were of the order of 8 billion barrels.

In October 1931 H. O. Caster,[2] president of the American Gas Association, in discussing developments in the natural-gas industry, stated that its capital investment had doubled in the last 5 years and totaled 2 billion dollars. He also estimated that 13 gas fields and gas-producing areas in the United States contained proved reserves of some 30 trillion cubic feet.

Garfias [3] estimated the proved reserves of natural gas at 40.0 trillion cubic feet at the end of 1934, equivalent to 20 years' supply on the basis of current consumption. Ley,[4] in 1935, estimated future recoverable gas from commercially proved and important areas as not less than 75 trillion cubic feet, and he pointed out that most of this reserve had been discovered and proved in the search for oil and that some part of this gas reserve would be wasted in producing oil.

Davis,[5] in a paper presented before the American Gas Association in May 1935, estimated the known natural-gas reserves of the United States to be 62 trillion cubic feet. He distributed these reserves among the several producing areas as follows:

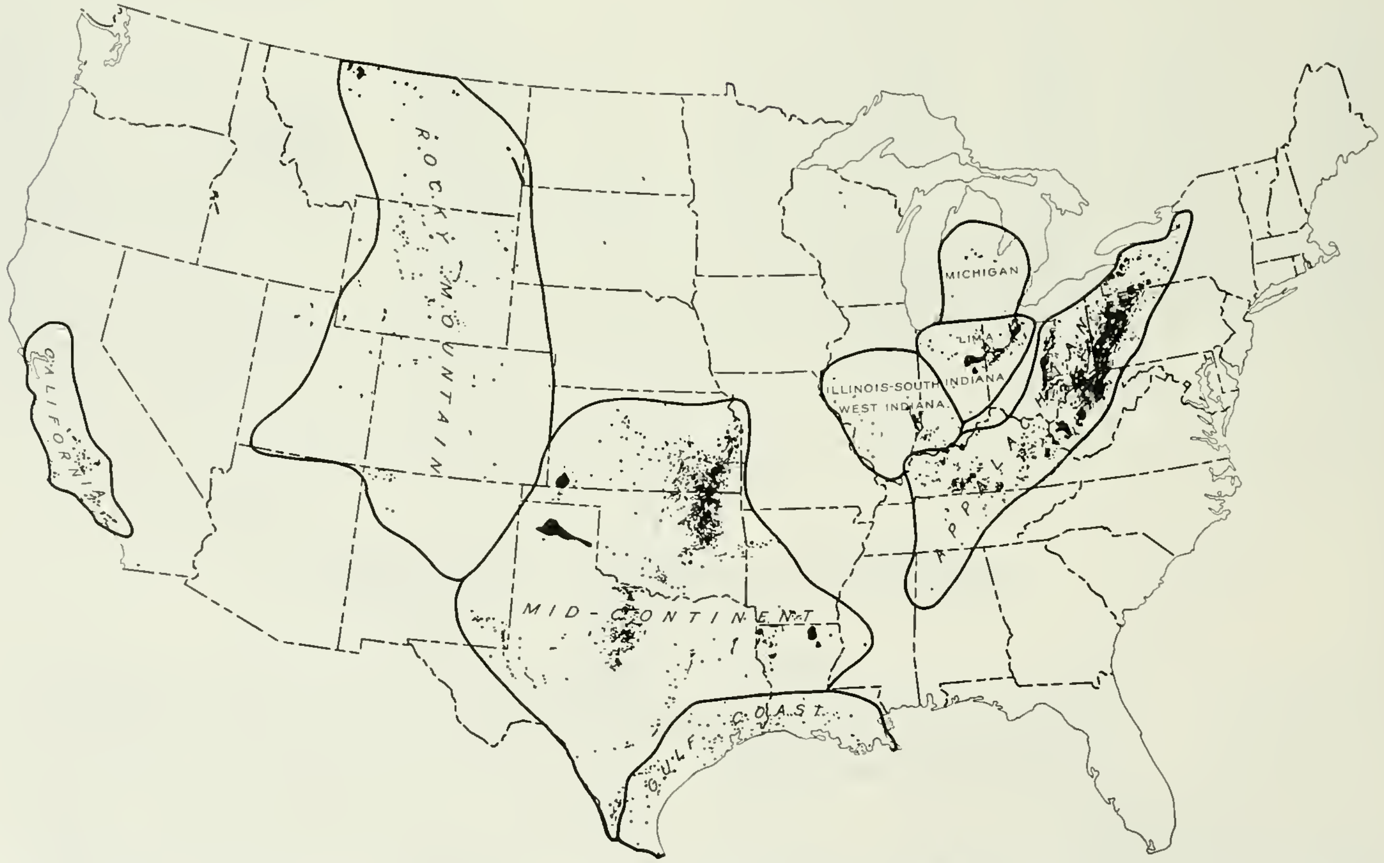

FIGURE 10.—Map of the United States Showing Natural Gas Fields and Producing Regions. Prepared by the Geological Survey, Department of the Interior.

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[1] Huntley, L. G., and Mason, S. L., "Gas and Coal Reserves in Relation to Pipe Line and Markets," *Nat. Petroleum News*, vol. 22, May 14, 1930, no. 20, pp. 34–36.

[2] Caster, H. O., "Developments in the Natural Gas Field," *Gas Age-Record*, vol. 68, Oct. 24, 1931, no. 17, pp. 613–630.

[3] Garfias, V. R., "Proven Reserves of Mineral Fuels in the United States." *Am. Inst. Min. Met. Eng. Trans.*, vol. 114, 1935, Petroleum division, pp. 243–244.

[4] Ley, H. A., *Geology of Natural Gas*, Am. Assoc. Petroleum Geol., June 1935. (Forward, p. vii, and Natural gas, pp. 1073–1149.)

[5] Davis, R. E., "Conservation of Natural Gas in the United States," *Gas Age-Record*, vol. 75, June 8, 1935, no. 23, pp. 565–572.

	Trillion cubic feet	Percent
Appalachian field	7.0	11.3
North Central States	.1	.2
Midcontinent and Gulf-coast fields	47.0	75.8
Rocky Mountain States	2.0	3.2
California	5.9	9.5
Total	62.0	100.0

The only notable exception to the Davis estimate is that of Hoots and Herold,[6] which placed the California reserves at 34 trillion cubic feet. If this apparently well substantiated estimate is accepted and totaled with the balance of the Davis estimate, the total for the United States should have been 90.1 trillion cubic feet and the percent distributed as follows: Midcontinent and Gulf coast, 52.2; California, 37.7; Appalachian, 7.8; Rocky Mountain States, 2.2; and North Central States, 0.1.

The discovery of important gas reservoirs since the date of the above estimates, notably by deeper drilling in California, the Rocky Mountain area, and in the North Central States, warrants the opinion that the known natural-gas reserves of the nation are at least of the order of a hundred trillion cubic feet, or in excess of 30 years' supply in terms of the present high rate of utilization.

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[6] Hoots, H. W., and Herold, S. C., "Natural gas resources of California," *Geology of Natural Gas*, American Association of Petroleum Geologists, June 1935, pp. 113–220.

PART TWO—SECTION II
WATER POWER RESOURCES OF THE UNITED STATES

CHAPTER 1.—UNDEVELOPED WATER POWER*

Nature of Water Power Resources

As a source of energy, water power affects and is affected by the available fuels, but differs from them in that it is not reduced by use. Water power is wasted if not used; to use it is, therefore, to conserve it. The quantity of water power that remains to be developed is strictly limited; its useful life is not. When the last pound of coal has been dug and burned, the power of falling water in the streams will continue to be available for human service.

As a use of water, power affects and is affected by the other functions and controls of water to which a stream may be adapted. Almost any considerable project for the control or use of an important stream will serve—or can serve—more than one useful purpose. There need be no conflict between the several purposes, including power, if the full possibilities of the stream are realized in the public interest. The objective is to develop each of the resources of a major stream in harmony with the others, to the end that the sum of the potential benefits to the public shall be a maximum.

Potential power in the streams.—The total potential average output of electric energy derivable from water power in the United States is at its theoretical maximum about 500 billion kilowatt-hours per year, according to a calculation based on estimates prepared by the United States Geological Survey.[1] This theoretical maximum is, of course, not attainable, since it would never be possible on many streams to pass all the flood waters through turbines.

Developed water power.—The total installed capacity of water wheels in electric generating plants in the United States on January 1, 1938, was 10,474,344 kilowatts. The output and installed capacity of these plants may be compared as follows:[2]

Installed capacity, Jan. 1, 1938, kilowatts	10,474,344
Output, year 1937, kilowatt-hours	43,702,000,000

The ratio of hydroelectric energy generated for public use to total energy generated for public use was 36.1 percent in 1937. This ratio has varied between 32.1 and 40.1 percent during the period of record, 1920–1937, depending largely on variations in stream flow and on the fact that hydroelectric plants are fully utilized during periods of depression.

Feasible undeveloped water power.—Water-power sites whose development probably will become economically feasible when a market for their output exists have been listed by the Federal Power Commission and summarized in a published report.[3] The same material, reclassified and slightly revised, is presented in table 1 below. This compilation was based on available data from various sources and especially on the "308" series of investigations by the Corps of Engineers.[4] The total average potential output of these sites is estimated at 273 billion kilowatt-hours per year. The total installed capacity would be 52,322,000 kilowatts, according to the engineering studies on which the estimate was based.

Estimates compared.—Recognizing that the several estimates were not made in the same manner nor on the same basis and are not strictly comparable, the total potential power in the streams, the actual developed power, and the feasible undeveloped power may be compared as follows:

	Annual output, billions of kilowatt-hours	Installed capacity, millions of kilowatts	Capacity factor, percent[1]
1. Total potential power	[2] 503.9	[3] 120 ±	
2. Developed power	[4] 43.7	[4] 10.5	47.5
3. Remaining undeveloped power[5]	460.2	110.2	
4. Feasible undeveloped power[6]	273.4	52.3	59.7
5. Total generation of electric energy for public use in 1937[7]	121.0	37.0	37.3

[1] Ratio of average output (kilowatt-hours per year divided by hours per year) to installed capacity.

[2] Derived from figures by the U. S. Geological Survey for power based on mean flow; see text footnote 1.

[3] Based on relation of installed capacity to 1937 output for existing hydroplants.

[4] Federal Power Commission, *Electric Power Statistics, 1937*, p. 3, p. 15. Output for 1937; capacity for Dec. 31, 1937. The capacity and output of plants producing power exclusively for private use is not included.

[5] Total potential power (line 1) minus developed power (line 2).

[6] Estimate by the Federal Power Commission, made originally for the National Power Survey (1935) and revised for this report. Includes partially developed sites.

[7] Fuel and water power; Federal Power Commission, *Electric Power Statistics, 1937*, p. 2. Output for 1937, capacity for Dec. 31, 1937.

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*By the Federal Power Commission.

[1] August 20, 1936. The Geological Survey figure is 82,180,000 kilowatts based on mean flow at 100 percent efficiency and gross head. At 70 percent over-all efficiency, including losses of head, the average output would be 503,900,000,000 kilowatt-hours per year.

[2] Federal Power Commission, *Electric Power Statistics 1937*, p. 15, p. 3. (The capacity of plants producing power exclusively for private use is not included.)

[3] Federal Power Commission, *National Power Survey*, Power Series No. 1, 1935; pp. 33–39.

[4] Investigations and reports authorized by the Rivers and Harbors Act of January 21, 1927, and H. Doc. No. 308, 69th Cong., 1st sess.

It is seen that the feasible undeveloped water-power sites of the United States are estimated to be capable of producing six times as much energy as those now developed, but only a little more than twice the energy produced in 1937 for public use by fuel and water power combined. It is also noted that 59 percent of the total theoretical undeveloped output and 47 percent of the total undeveloped capacity has been estimated as probably economically feasible when markets for the potential output exist.

Feasible Undeveloped Water Power

Estimated total available.—Table 1 summarizes the average annual output estimated to be available at the principal undeveloped hydroelectric sites which have been studied by various public and private agencies, and which apparently will have economic merit when a need for their power output exists.[5] Most of the information underlying this compilation was obtained from published and unpublished reports by the Department of War made under the authority of the Rivers and Harbors Act of January 21, 1927, and House Document Numbered 308, Sixty-ninth Congress, first session.

Limitations of the estimate.—The accuracy of this selection of hydroelectric sites as having present or future economic merit is necessarily limited by the accuracy of the available information on physical conditions at each site and also by the uncertainty that attends any forecast of future power costs and requirements in a given area. Installations of less than about 1,500 kilowatts have, in general, been omitted as being statistically unimportant, although they may be highly desirable for local reasons. The power possibilities of multiple-purpose developments are not adequately represented. The test of economic merit, in general, was the estimated cost of capacity and energy from an alternative fuel-electric source delivered at an assumed load center.

Figures proposed for the installed generating capacities at the various sites have been included in the summary to give an idea of the relative size of the projects, although the actual capacity that should be installed at each project depends on the characteristics of the load to be served and other special conditions which cannot be definitely established far in advance of construction.

In originally presenting such an estimate of feasible undeveloped water power in 1935, the Federal Power Commission made important qualifying reservations to which the reader is referred.[6] Nevertheless, these published and revised figures represent the best available summary of feasible undeveloped water power in the United States.

Factors Affecting Feasibility.—The factors that may make an individual water-power site economically feasible at some future time are not capable of accurate evaluation, even for the relatively near future. Specific conclusions as to individual sites may change as better information is obtained with the passage of time. The economic feasibility of a given hydroelectric project has usually been gaged by comparison with the cost of power from an alternative fuel-electric source; but this depends at any given time largely on the relation between the then cost of money, on the one hand, and the price of fuel and compensation of labor on the other. Hydroelectric generating costs are governed largely by the cost of money, while fuel-electric generating costs are governed largely by the price of fuel, which includes the compensation of labor necessary to produce and transport the fuel, and by the compensation of labor necessary to operate the plant.

Economic feasibility depends on cost and revenue. The construction cost cannot accurately be determined until the site has been adequately explored and detailed designs and estimates have been prepared. The potential revenue depends on the characteristics of the power output from the project (capacity and energy available at each hour of the day, each day of the week, and each week of the year) and on the existence of a market for the power—a market the location, size, and characteristics of which must be determined for each project and area on the basis of existing loads and possible growth in load, and on the competitive cost of fuel-generated energy delivered to the same market.

In addition, it appears quite possible that power developments may become desirable at water-control projects—such as flood-control and irrigation dams—many of which are not included in the sites on which the figures here given were based. Development of power as an incident to other purposes might bring many additional sites into economic feasibility. (Cont'd p. 305)

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[5] Revised and reclassified from estimates made and originally published by the Federal Power Commission, *National Power Survey, Interim Report*, 1935.

[6] "The tentative summary * * * should not be considered as precise or final. Adequate field surveys of many of the streams studied are not available. In some cases the records of stream flow do not cover a sufficient length of time to permit reliable conclusions. At some sites the factors which determine the proper size of installation are unknown and can only be derived by further and more exhaustive studies. Every effort, however, has been made to have the figures presented represent a sound but conservative estimate of undeveloped water power. Preliminary studies of other reports show that the development of many of the sites which they include probably cannot be economically justified. These sites have not been included in the figures presented in this report. It is possible that more complete study will show that additional sites should be eliminated from consideration. It is equally possible that more detailed information will show that the values of power output and capacity assigned to many of the sites which are included in the figures presented have been too conservative."—Federal Power Commission, *National Power Survey, Interim Report*, 1935, p. 33.

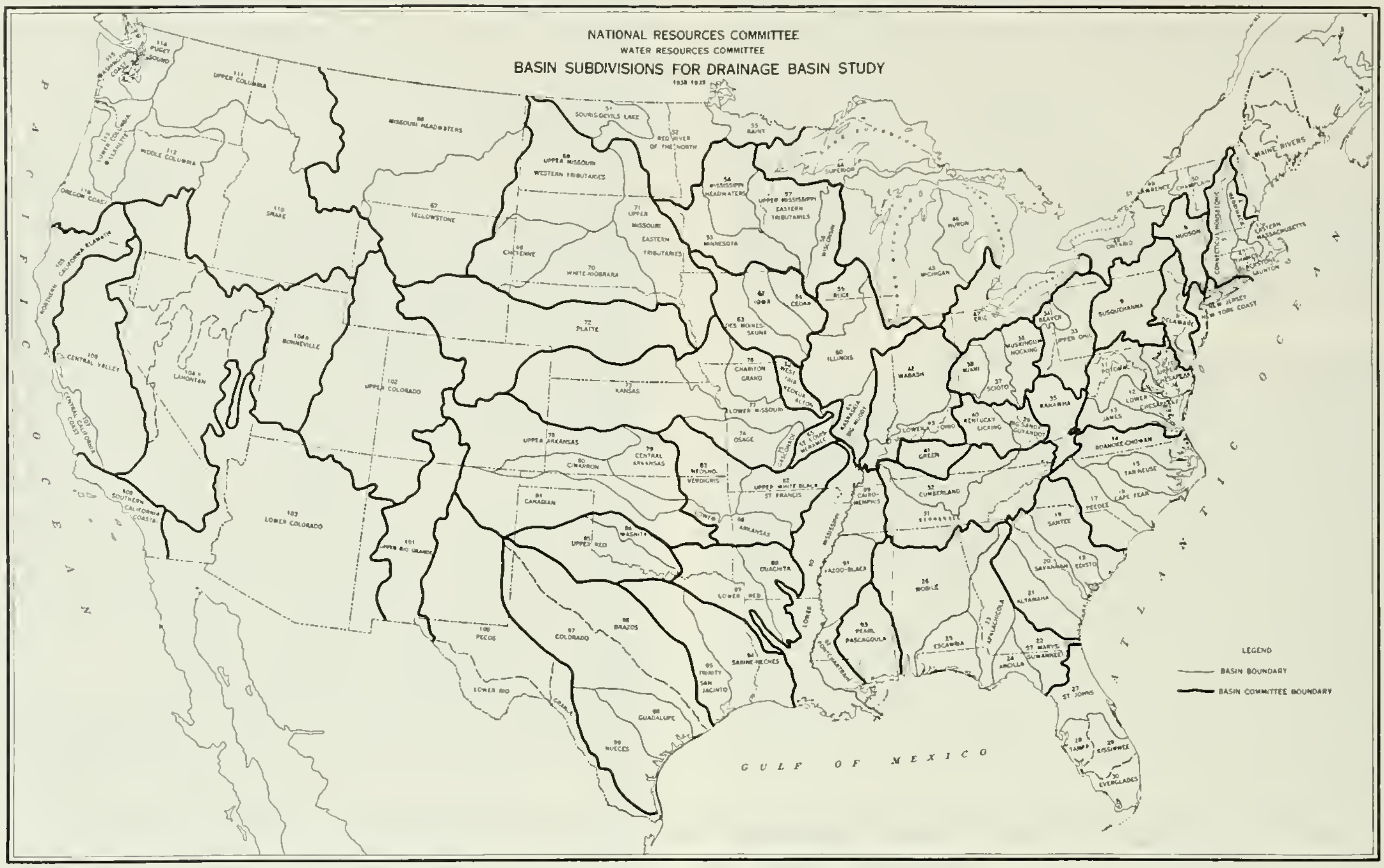

FIGURE 1.—Map Showing Drainage Basins as Used in Table 1.

TABLE 1.—*Undeveloped water power in the United States, 1938*

SUMMARY BY REGIONAL GROUPS, UNITED STATES DRAINAGE BASINS

[Note that these regional groups are not the same as the Census regions shown in table 2]

Regional group (1)	Proposed installations: Number of projects (2)	Proposed installations: Generating capacity, thousands of kilowatts (3)	Proposed installations: Average annual output, millions of kilowatt-hours (4)
New England basins	121	940.0	3,704.9
North Atlantic basins	32	2,114.5	4,508.5
Middle Atlantic basins	97	2,196.3	7,838.0
Southeast basins	63	1,537.9	4,914.5
Tennessee Valley basin	154	4,085.6	14,492.7
Ohio River basin	90	3,987.4	14,766.3
Great Lakes basin	245	2,195.6	12,471.7
Upper Mississippi basin	84	466.4	2,124.5
Missouri basin	52	2,617.1	9,685.4
Southwest Mississippi basin	61	1,366.1	5,754.5
Lower Mississippi basin	12	134.2	712.0
Western Gulf basins	23	132.4	703.6
Colorado River basin	110	4,732.0	26,070.4
The Great basin	8	52.0	207.1
California basins	249	6,454.5	34,903.3
Pacific Northwest basins	730	19,309.9	130,519.5
Grand total	2,131	52,321.9	273,376.9

TABLE 1.—*Undeveloped water power in the United States, 1938*—Continued

SUMMARY BY STATES

(1)	Proposed installations: Generating capacity, thousands of kilowatts (2)	Proposed installations: Average annual output, millions of kilowatt-hours (3)
Alabama	1,238.6	4,285.8
Arizona	2,377.2	12,315.9
Arkansas	581.7	2,255.2
California	6,411.5	34,968.4
Colorado	299.3	2,300.7
Connecticut	116.2	457.6
Delaware	0	0
Florida	0	0
Georgia	817.4	2,617.4
Idaho	2,533.6	19,908.6
Illinois	111.5	516.8
Indiana	249.0	477.0
Iowa	127.1	515.8
Kansas	0	0
Kentucky	792.7	2,855.5
Louisiana	196.4	1,064.0
Maine	364.9	1,608.7
Maryland	728.0	1,834.5
Massachusetts	48.8	137.0
Michigan	267.5	1,014.9
Minnesota	194.2	988.6
Mississippi	127.4	655.3

TABLE 1.—*Undeveloped water power in the United States, 1938*—Continued

SUMMARY BY STATES—Continued

	Proposed installations	
	Generating capacity, thousands of kilowatts	Average annual output, millions of kilowatt-hours
(1)	(2)	(3)
Missouri	202.5	814.2
Montana	2,481.5	10,283.0
Nebraska	40.2	316.0
Nevada	548.7	2,564.2
New Hampshire	234.4	939.7
New Jersey	113.2	362.5
New Mexico	38.0	250.5
New York	1,845.1	10,892.8
North Carolina	1,144.8	3,808.5
North Dakota	0	0
Ohio	22.3	84.5
Oklahoma	341.9	1,559.4
Oregon	5,152.8	34,487.3
Pennsylvania	1,489.5	2,983.6
Rhode Island	0	0
South Carolina	582.5	2,201.5
South Dakota	13.6	54.6
Tennessee	2,964.8	11,713.6
Texas	254.7	1,048.6
Utah	1,443.5	8,257.0
Vermont	418.1	1,365.5
Virginia	1,366.1	4,481.6
Washington	11,214.4	72,709.0
West Virginia	1,035.0	7,121.5
Wisconsin	210.6	975.9
Wyoming	589.2	2,964.2
District of Columbia	91.5	270.0
Grand total	52,321.9	273,376.9

NEW ENGLAND DRAINAGE BASINS

Basin	State	Number of projects	Proposed installations	
			Generating capacity, thousands of kilowatts	Average annual output, millions of kilowatt-hours
(1)	(2)	(3)	(4)	(5)
Androscoggin	Maine	8	40.2	158.3
Do	New Hampshire	9	45.5	288.9
Total, Androscoggin.		17	85.7	447.2
Connecticut	Connecticut	1	36.0	229.5
Do	Massachusetts	4	40.5	112.3
Do	New Hampshire	10	18.1	53.7
Do	New Hampshire-Vermont.	7	208.6	642.8
Do	Vermont	19	70.4	235.3
Total, Connecticut.		41	373.6	1,273.6
Housatonic	Connecticut	6	70.2	186.5
Do	Connecticut-New York.	1	2.0	10.4
Total, Housatonic.		7	72.2	196.9
Kennebec	Maine	18	188.5	815.5
Machias	do	2	1.4	5.5

TABLE 1.—*Undeveloped water power in the United States, 1938*—Continued

NEW ENGLAND DRAINAGE BASINS—Continued

Basin	State	Number of projects	Proposed installations	
			Generating capacity, thousands of kilowatts	Average annual output, millions of kilowatt-hours
(1)	(2)	(3)	(4)	(5)
Merrimack	Massachusetts	1	6.3	18.1
Do	New Hampshire	11	66.5	275.7
Total, Merrimack		12	72.8	293.8
Penobscot	Maine	8	114.7	550.7
Saco	do	3	12.1	47.2
St. Croix	do	3	7.3	28.7
Thames	Connecticut	4	9.0	36.4
Do	Massachusetts	3	2.0	6.6
Total, Thames		7	11.0	43.0
Union		3	.7	2.8
Total, New England basins.		121	940.0	3,704.9

NORTH ATLANTIC DRAINAGE BASINS

Basin	State	Number of projects	Generating capacity, thousands of kilowatts	Average annual output, millions of kilowatt-hours
Delaware	New Jersey-Pennsylvania.	3	226.4	725.0
Do	New York	1	27.2	57.0
Do	New York-Pennsylvania.	4	74.4	366.0
Total, Delaware		8	328.0	1,148.0
Hudson	New York	16	288.5	942.7
Lehigh	Pennsylvania	1	128.0	380.0
Susquehanna	Maryland	1	364.0	609.0
Do	Pennsylvania	6	1,006.0	1,428.8
Total, Susquehanna.		7	1,370.0	2,037.8
Total, North Atlantic basins.		32	2,114.5	4,508.5

MIDDLE ATLANTIC DRAINAGE BASINS

Basin	State	Number of projects	Generating capacity, thousands of kilowatts	Average annual output, millions of kilowatt-hours
Cape Fear	North Carolina	5	132.0	295.0
James	Virginia	12	96.2	372.0
York	do	5	18.7	53.0
Pee Dee	North Carolina	8	237.4	1,031.0
Potomac	District of Columbia-Virginia.	1	183.0	540.0
Do	Maryland	1	11.0	32.0
Do	Maryland-Virginia	3	420.0	1,299.0
Do	Maryland-West Virginia.	3	152.0	453.0
Do	Virginia	14	97.0	393.0
Do	West Virginia	8	175.0	503.0
Total, Potomac		30	1,038.0	3,220.0
Rappahannock	Virginia	11	82.8	259.0
Roanoke	North Carolina	3	46.0	169.0
Do	North Carolina-Virginia.	3	120.6	459.0
Do	Virginia	11	117.8	562.0
Total, Roanoke		17	284.4	1,190.0

TABLE 1.—*Undeveloped water power in the United States, 1938*—Continued

MIDDLE ATLANTIC DRAINAGE BASINS—Continued

Basin	State	Number of projects	Proposed installations	
			Generating capacity, thousands of kilowatts	Average annual output, millions of kilowatt-hours
(1)	(2)	(3)	(4)	(5)
Santee	North Carolina	1	18.2	77.0
Do	South Carolina	8	288.6	1,341.0
Total, Santee		9	306.8	1,418.0
Total, Middle Atlantic basins.		97	2,196.3	7,838.0

SOUTHEAST DRAINAGE BASINS

Basin	State	Number of projects	Generating capacity, thousands of kilowatts	Average annual output, millions of kilowatt-hours
Altamaha	Georgia	5	93.5	361.6
Apalachicola	Alabama-Georgia	3	165.0	451.0
Do	Georgia	5	144.0	423.0
Total, Apalachicola		8	309.0	874.1
Mobile	Alabama	1	49.5	132.8
Do	Georgia	8	147.4	532.8
Black Warrior	Alabama	13	183.1	545.5
Tombigbee	do	5	92.6	448.4
Do	Mississippi	8	33.3	145.4
Total, Mobile		35	505.9	1,804.9
Savannah	Georgia	3	72.7	219.2
Do	Georgia-South Carolina.	11	525.4	1,588.3
Do	South Carolina	1	31.4	66.5
Total, Savannah		15	629.5	1,874.0
Total, Southeast basins.		63	1,537.9	4,914.5

TENNESSEE DRAINAGE BASIN

Basin	State	Number of projects	Generating capacity, thousands of kilowatts	Average annual output, millions of kilowatt-hours
T. V. A. approved projects:				
Main stream	Alabama	3	800.4	2,819.0
	Kentucky	1	160.0	564.0
	Tennessee	4	534.0	1,882.0
Tributaries	North Carolina	1	120.0	320.0
	Tennessee	1	100.8	965.0
Total T. V. A projects		10	[1] 1,715.2	6,550.0
Other projects: Tributaries.	Alabama	5	30.4	114.6
	Georgia	2	14.5	61.0
	Mississippi	1	8.0	34.4
	North Carolina	38	530.8	1,777.0
	Tennessee	91	1,754.9	5,818.6
	Virginia	7	31.8	137.1
Total, other projects.		144	2,370.4	7,942.7
Total, Tennessee Basin.		154	4,085.6	14,492.7

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[1] Includes present installations as follows:

Main stream: Alabama, 246; Kentucky, 0; Tennessee, 72. Tributaries: North Carolina, 0; Tennessee, 100; Total, 418, and also the capacity of future units that could be added in empty stalls now provided.

TABLE 1.—*Undeveloped water power in the United States, 1938*—Continued

OHIO DRAINAGE BASIN

Basin	State	Number of projects	Proposed installations	
			Generating capacity, thousands of kilowatts	Average annual output, millions of kilowatt-hours
(1)	(2)	(3)	(4)	(5)
Big Sandy	Kentucky	2	21.3	116.0
Do	Kentucky-Virginia	1	24.7	61.0
Do	Kentucky-West Virginia.	1	16.3	88.0
Do	Virginia	3	83.4	194.0
Total, Big Sandy		7	145.7	459.0
Cheat	West Virginia	15	643.8	1,524.5
Clarion	Pennsylvania	4	205.2	629.3
Cumberland	Kentucky	5	358.7	1,461.8
Do	Tennessee	8	575.1	3,048.0
Total, Cumberland		13	933.8	4,509.8
Green	Kentucky	7	71.9	175.2
Kanawha	Virginia	13	464.4	1,332.0
Do	West Virginia	14	1,009.9	4,739.0
Total, Kanawha		27	1,474.3	6,071.0
Kentucky	Kentucky	8	160.2	464.0
Ohio	Ohio-West Virginia	1	44.5	169.0
Wabash	Indiana	5	241.0	447.0
Youghiogheny	Maryland	3	67.0	317.5
Total, Ohio Basin		90	3,987.4	14,766.3

GREAT LAKES DRAINAGE BASIN

Basin	State	Number of projects	Generating capacity, thousands of kilowatts	Average annual output, millions of kilowatt-hours
Au Sable	Michigan	6	56.7	156.9
Ausable	New York	7	31.9	139.5
Bad	Wisconsin	2	7.8	43.0
Baptism and Manitou	Minnesota	1	11.4	60.0
Beaver Bay	do	1	2.5	15.0
Black	New York	3	0	265.0
Brule	Minnesota	5	20.3	109.0
Do	Wisconsin	1	2.3	16.0
Cascade	Minnesota	1	5.6	26.8
Devil Track	do	2	5.5	24.7
Genesee	New York	3	247.8	454.0
Lamoille	Vermont	14	45.5	144.1
Manistee	Michigan	9	87.4	211.3
Menominee	Michigan	10	15.5	101.0
Do	Michigan-Wisconsin	10	51.5	263.0
Do	Wisconsin	1	2.1	12.0
Total, Menominee		21	69.1	376.0
Missisquoi	Vermont	13	49.3	196.1
Montreal	Michigan-Wisconsin	2	4.5	22.0
Do	Wisconsin	1	3.1	15.0
Total, Montreal		3	7.6	37.0
Moose	New York	5	95.0	502.5
Muskegon	Michigan	8	29.6	142.0
Niagara	New York	1	160.0	1,140.0
Oconto	Wisconsin	3	5.7	30.0
Ontonagon	Michigan	7	24.3	126.2
Otter Creek	Vermont	16	60.8	233.2
Peshtigo	Wisconsin	3	15.4	73.1
Pigeon	Minnesota	5	23.2	100.6
Poplar and Temperance	do	2	11.9	64.0

TABLE 1.—*Undeveloped water power in the United States, 1938*—Continued

GREAT LAKES DRAINAGE BASIN—Continued

Basin (1)	State (2)	Number of projects (3)	Proposed installations: Generating capacity, thousands of kilowatts (4)	Proposed installations: Average annual output, millions of kilowatt-hours (5)
Poultney	New York-Vermont	2	5.7	23.8
Do	Vermont	4	1.9	7.3
Total, Poultney		6	7.6	31.1
Raquette	New York	17	65.3	623.1
Saranac	do	21	33.6	177.2
St. Joseph	Indiana	3	8.0	30.0
Do	Michigan	2	7.2	30.0
Total, St. Joseph		5	15.2	60.0
St. Lawrence	New York	1	820.0	6,115.0
St. Louis	Minnesota	3	8.5	79.4
St. Regis	New York	24	34.6	276.7
Sturgeon	Michigan	5	18.6	105.0
Wimooski	Vermont	15	83.1	216.2
Wolf	Wisconsin	6	32.5	102.0
Total, Great Lakes Basin		245	2,195.6	12,471.7

UPPER MISSISSIPPI DRAINAGE BASIN

Basin (1)	State (2)	Number of projects (3)	Proposed installations: Generating capacity, thousands of kilowatts (4)	Proposed installations: Average annual output, millions of kilowatt-hours (5)
Big Fork	Minnesota	4	6.5	25.9
Black	Wisconsin	1	2.5	6.0
Chippewa	do	13	60.7	279.1
Des Moines	Iowa	9	37.7	148.0
Do	Iowa-Missouri	1	17.2	81.0
Total, Des Moines		10	54.9	229.0
Illinois	Illinois	8	85.1	385.5
Iowa	Iowa	16	80.8	327.3
Little Fork	Minnesota	4	6.9	29.2
Mississippi, upper	do	9	71.1	363.5
Rock	Illinois	6	26.4	131.3
Do	Wisconsin	2	1.7	8.0
Total, Rock		8	28.1	139.3
St. Croix	Minnesota-Wisconsin	1	30.0	125.5
Do	Wisconsin	1	3.0	9.0
Total, St. Croix		2	33.0	134.5
Vermillion	Minnesota	2	5.8	27.8
Wisconsin	Wisconsin	7	31.0	177.4
Total, upper Mississippi basins.		84	466.4	2,124.5

MISSOURI DRAINAGE BASIN

Basin (1)	State (2)	Number of projects (3)	Proposed installations: Generating capacity, thousands of kilowatts (4)	Proposed installations: Average annual output, millions of kilowatt-hours (5)
Big Hole	Montana	1	50.0	151.0
Cheyenne	South Dakota	4	13.6	54.6
Gallatin	Montana	3	24.0	110.0
Gasconade	Missouri	4	85.0	359.8
Madison	Montana	2	23.8	152.0
Missouri, upper	do	10	1,434.0	4,346.0
Platte	Colorado	2	19.1	96.0
Do	Nebraska	3	40.2	316.0
Do	Wyoming	8	210.5	827.0
Total, Platte		13	269.8	1,239.0
Yellowstone	Montana	4	449.0	1,720.0
Do	Wyoming	11	267.9	1,553.0
Total, Yellowstone		15	716.9	3,273.0
Total, Missouri basins.		52	2,617.1	9,685.4

SOUTHWEST MISSISSIPPI DRAINAGE BASIN

Basin (1)	State (2)	Number of projects (3)	Proposed installations: Generating capacity, thousands of kilowatts (4)	Proposed installations: Average annual output, millions of kilowatt-hours (5)
Arkansas, upper	Colorado	1	25.0	103.0
Cimarron	Oklahoma	1	13.5	41.0
Grand	Missouri	1	1.0	4.9
Do	Oklahoma	4	132.8	890.4
Total, Arkansas		7	172.3	1,039.3
Ouachita	Arkansas	3	28.5	130.2
Red, lower	do	6	69.5	340.0
Do	Louisiana	8	115.0	659.0
Do	Louisiana-Texas	3	47.0	253.0
Do	Oklahoma	5	56.6	146.0
Do	Oklahoma-Texas	10	278.0	964.0
Do	Texas	1	7.6	29.0
Total, Red		33	573.7	2,391.0
White, upper	Arkansas	13	443.7	1,640.0
Do	Missouri	1	81.0	308.0
White, lower	Arkansas	2	40.0	145.0
White, lower, Black	Missouri	2	26.9	101.0
Total, White		18	591.6	2,194.0
Total, southwest Mississippi Basin		61	1,366.1	5,754.5

LOWER MISSISSIPPI DRAINAGE BASIN

Basin (1)	State (2)	Number of projects (3)	Proposed installations: Generating capacity, thousands of kilowatts (4)	Proposed installations: Average annual output, millions of kilowatt-hours (5)
Pearl	Louisiana	3	41.7	205.0
Do	Louisiana-Mississippi	1	12.7	63.0
Do	Mississippi	8	79.8	444.0
Total, Pearl		12	134.2	712.0
Total, lower Mississippi Basin		12	134.2	712.0

TABLE 1.—*Undeveloped water power in the United States, 1938*—Continued

WESTERN GULF DRAINAGE BASIN

Basin (1)	State (2)	Number of projects (3)	Proposed installations: Generating capacity, thousands of kilowatts (4)	Proposed installations: Average annual output, millions of kilowatt-hours (5)
Brazos	Texas	7	62.1	295.3
Calcasieu	Louisiana	4	9.8	42.0
Guadalupe	Texas	8	22.5	115.8
Rio Grande, upper	New Mexico	4	38.0	250.5
Total, western Gulf basins		23	132.4	703.6

COLORADO BASIN

Basin (1)	State (2)	Number of projects (3)	Proposed installations: Generating capacity, thousands of kilowatts (4)	Proposed installations: Average annual output, millions of kilowatt-hours (5)
Main Stream	Arizona	3	1,459.0	7,643.5
Do	Arizona-California	1	80.0	526.0
Do	Arizona-Nevada	2	1,097.5	5,128.5
Do	Colorado	2	58.5	476.9
Do	Utah	3	607.8	3,294.6
All-American Canal	California	8	65.0	502.2
Aqueduct	do	1	21.0	175.0
Tributaries:				
Blue	Colorado	3	9.8	71.9
Dolores	Colorado-Utah	1	12.8	112.1
Eagle	Colorado	2	7.0	50.6
Gila	Arizona	26	272.1	1,593.9
Greene	Colorado	6	93.4	816.4
Do	Utah	26	714.3	4,248.5
Little Colorado	Arizona	5	57.3	251.2
Roaring Fork	Colorado	11	51.7	402.6
San Juan	Utah	4	96.4	549.3
San Miguel	Colorado	3	9.7	73.5
Taylor	do	3	18.7	153.7
Total, Colorado Basin		110	4,732.0	26,070.4

THE GREAT BASIN

Basin (1)	State (2)	Number of projects (3)	Proposed installations: Generating capacity, thousands of kilowatts (4)	Proposed installations: Average annual output, millions of kilowatt-hours (5)
Bear	Idaho	2	33.4	98.5
Do	Utah	1	5.7	4.4
Weber	do	5	12.9	104.2
Total, Great Basin		8	52.0	207.1

CALIFORNIA DRAINAGE BASINS

TABLE 1.—*Undeveloped water power in the United States, 1938*—Continued

CALIFORNIA DRAINAGE BASINS—Continued

Basin (1)	State (2)	Number of projects (3)	Proposed installations: Generating capacity, thousands of kilowatts (4)	Proposed installations: Average annual output, millions of kilowatt-hours (5)
Eel	California	13	218.0	1,156.8
Gordon Creek	do	2	20.0	98.6
Klamath:				
Main Stem	do	13	1,115.4	7,229.0
Do	Oregon	4	169.0	875.1
Trinity	California	11	393.0	2,011.5
Total Klamath		28	1,677.4	10,115.6
Mad	California	7	79.0	403.0
Owens	do	17	118.2	669.3
Russian	do	1	1.5	12.2
Sacramento:				
Main stem	do	6	507.2	2,606.2
American	do	25	517.0	2,037.4
Bear	do	3	54.0	307.9
Deer Creek	do	5	60.0	394.0
Feather	do	22	808.6	3,817.0
McCloud	do	4	221.5	1,171.2
Pit	do	9	360.0	1,987.3
Yuba	do	21	171.9	1,013.9
Total, Sacramento		95	2,700.2	13,334.9
Salton Sea: Snow Creek	California	2	2.8	9.4
San Joaquin:				
Main stem	do	26	304.8	1,373.9
Kings	do	20	710.0	4,096.7
Merced	do	7	59.5	270.5
Mokelumne	do	3	56 5	377.8
Stanislaus	do	16	231.0	1,550.1
Toulumne	do	10	184.1	976.5
Total, San Joaquin		82	1,545.9	8.645.5
Smith	California	2	91.5	458.0
Total, California basins		249	6,454.5	34,903.3

PACIFIC NORTHWEST DRAINAGE BASINS—Continued

Basin (1)	State (2)	Number of projects (3)	Proposed installations: Generating capacity, thousands of kilowatts (4)	Proposed installations: Average annual output, millions of kilowatt-hours (5)
Columbia, main stem	Oregon-Washington	5	1,644.8	10,497.1
Do	Washington	6	6,449.8	42,160.5
Columbia, tributaries:				
Chelan	do	3	37.3	267.1
Clark Fork	Idaho	3	102.5	834.0
Do	Montana	4	183.4	1,191.4
Do	Washington	1	448.0	3,081.6
Cowlitz	do	17	377.4	2,988.6
Deschutes	Oregon	20	508.1	3,779.0
Entiat	Washington	2	5.7	42.9
Flathead	Montana	6	284.0	2,362.8
John Day	Oregon	7	46.6	376.0
Klickitat	Washington	13	118.8	907.8
Kootenai	Idaho	1	21.4	161.2
Do	Montana	1	33.3	249.8
Lewis	Washington	15	356.0	1,751.5
Little White Salmon	do	2	26.9	177.8
Okanogan	do	3	10.3	77.1
Sandy	Oregon	12	67.1	455.0
Sheep Creek	Washington	2	5.6	48.0
Snake. (See following.)				
Spokane	Idaho	2	12.7	94.6
Do	Washington	2	28.6	225.1
Wenatchee	do	16	244.9	2,041.3
White Salmon	do	8	61.4	469.9
Willamette. (See following.)				
Yakima	do	23	168.6	1,335.7
Total, Columbia, except Snake and Willamette.		174	11,243.2	75,575.8

TABLE 1.—*Undeveloped water power in the United States, 1938*—Continued

PACIFIC NORTHWEST DRAINAGE BASINS

Basin (1)	State (2)	Number of projects (3)	Proposed installations: Generating capacity, thousands of kilowatts (4)	Proposed installations: Average annual output, millions of kilowatt-hours (5)
Snake, main stem	Idaho	26	666.1	5,399.6
Do	Idaho-Oregon	5	775.8	6,165.0
Do	Washington	4	271.3	2,376.6
Do	Wyoming	4	110.8	584.2
Snake, tributaries:				
Boise	Idaho	14	45.3	375.0
Clearwater	do	40	281.3	2,070.9
Grande Ronde	Oregon	9	84.7	640.7
Do	Washington	4	62.5	529.9
Henrys Fork	Idaho	7	83.6	678.9
Imnaha	Oregon	5	45.1	368.8
Payette	Idaho	19	113.7	855.7
Salmon	do	106	785.7	6,257.7
Total, Snake		243	3,325.9	26,303.0
Willamette:				
Coast Fork	Oregon	7	9.8	70.0
Middle Fork	do	17	229.4	1,203.9
McKenzie	do	22	348.8	2,093.7
Santiam, North	do	9	200.2	1,157.6
Santiam, South	do	10	55.0	402.5
Molalla	do	11	45.7	305.1
Clackamas	do	10	168.6	1,298.3
Total, Willamette		86	1,057.5	6,531.1
Total, Columbia Basin.		603	15,626.6	108,409.9
Puget Sound:				
Cedar	Washington	2	6.1	42.9
Dosewallips	do	3	26.6	162.7
Duckabush	do	3	20.4	144.3
Dungeness	do	6	24.4	159.9
Elwha	do	8	65.8	522.7
Hamma Hamma	do	1	12.0	89.3
Lilliwaup Creek	do	1	2.0	17.5
Nisqually	do	7	59.0	478.9
Nooksack	do	5	135.1	869.4
Puyallup	do	16	127.9	846.6
Quilceoe	do	3	7.7	54.1
Skagit	do	26	1,254.0	5,424.9
Skokomish	do	4	41.9	267.8
Skykomish	do	18	243.6	1,678.9
Snoqualmie	do	5	146.7	893.7
Stillaquamish	do	10	135.0	825.4
Total, Puget Sound		118	2,308.2	12,479.0
Oregon Coast:				
Coquille	Oregon	5	30.7	265.6
Nehalem	do	3	174.0	761.0
Nestucca	do	6	11.6	87.6
Rogue	do	29	408.2	3,291.3
Siuslaw	do	4	55.0	246.9
Trask	do	7	13.6	95.6
Umpqua	do	25	430.8	3,016.0
Wilson	do	6	18.1	118.0
Total, Oregon coast		85	1,142.0	7,882.0
Washington coast:				
Chehalis	Washington	4	26.8	223.7
Hoh	do	10	101.1	813.6
North	do	1	20.0	87.6

TABLE 1.—*Undeveloped water power in the United States, 1938*—Continued

SOUTHEAST DRAINAGE BASINS—Continued

Basin (1)	State (2)	Number of projects (3)	Proposed installations: Generating capacity, thousands of kilowatts (4)	Proposed installations: Average annual output, millions of kilowatt-hours (5)
Washington coast—Con.				
Ozette	do	1	.8	6.6
Quinault	do	5	42.3	292.4
Soleduc—Lyre	do	3	42.1	324.7
Total, Washington coast.		24	233.1	1,748.6
Total, northwest basins.		730	19,309.9	130,519.5

Any such broad compilation as that given in table 1 should therefore not be considered precise or final; changes in the cost of money, the cost of labor, the cost of fuel, the location of the power market, or the characteristics of the power load might greatly affect the classification of many known undeveloped water-power sites.

Subject to these qualifications, the summary presented in table 1 is an approximate measure of the principal undeveloped water-power resources of the United States.

Long-distance transmission; technological possibilities.—Technological changes now in prospect that may affect the feasibility of water power include those relating to long-distance transmission of electric energy. Repeatedly, the engineering limit of transmission has been driven back. Twenty years ago, it was generally felt that the practical engineering limit had probably been reached and that that limit was about 200 miles. Ten years ago, a bold designer would have placed the distance at perhaps 300 miles. Today it is known that we can design, build, and operate lines longer than are justified by immediate economic conditions. When power can be transmitted economically several hundred or a thousand miles, important water-power sources will become available that are now too distant from existing markets to be considered.

Transmission in the near future of larger amounts of power to much greater distances and at higher voltages than at present is already definitely foreshadowed by the bold engineering advances that made possible the 266-mile heavy-duty line now operating successfully at 287,000 volts between Los Angeles and Boulder Dam. This line was pioneered, designed, built, and is being operated by engineers of the city of Los Angeles with the cooperation of the United States Bureau of Reclamation. High-tension transmission of direct-current power, now in a late experimental stage, may further widen the technical limit of transmission distance and reduce the cost.

Other technological investigations suggest the possibility of new or improved processes in our basic industries that may require large quantities of low-cost power such as may be made available by some of the great water projects of the future, utilizing local raw materials and perhaps creating virtually new industries where no such activity now exists.[7]

The duty of multiple-purpose developments.—There are rich possibilities for the development of water power as a joint purpose, in combination with other useful purposes to which a stream may be adapted or in combination with measures to control the stream for other reasons. It is probable that many of the original studies from which water-power sites were selected for inclusion in table 1 failed to give full weight to such possibilities of multiple-purpose development.

Historically it is true that water-power developments have sometimes been permitted that impaired the usefulness of certain streams for other purposes and certain streams may have been exploited in such manner as to foreclose or reduce their future usefulness for power. More recently it has been discovered that this apparent conflict can largely be resolved on many streams, and especially on great river systems, if these resources are properly utilized and wisely controlled.

It is the duty and the task of the designer and of those who guide the application of public policy to develop all of the potential benefits of great river systems in such manner that their sum shall be a maximum. Each should be and can be developed in harmony with the others; each should contribute its share to obtain a total benefit much larger than would be possible by separate exploitation, and this at lower total cost.

Regional Significance

Power requirements of the relatively near future will make necessary new supplies of energy exceeding the potential output of all the available and feasible undeveloped water-power sites in most industrial regions. A relatively small growth in the power load, surely to be expected under anything like normal conditions, will bring this to pass in a very few years. The conclusion is inescapable that the potential output from any undeveloped water-power site in these regions can be absorbed by the power requirements of the near future, if it can be delivered to the load and sold at competitive prices.

The total amount of potential and feasible undeveloped water power within present economic transmission distance of the larger industrial and urban areas in the eastern half of the country would not, in fact, supply even their present needs for electric energy without the aid of fuel.

In 13 years, the increase in power load would require annually an amount of energy larger than the entire average output of all the feasible undeveloped water sites east of the Mountain and Pacific States, if the rate of growth actually experienced in this region from 1921 to 1929 and again from 1932 to 1937 should continue. By including the tremendous resources of the Mountain and Pacific States and the relatively low increments of power growth they have so far experienced, the indicated period is extended to 40 years. In the Middle Atlantic States—New York, New Jersey, and Pennsylvania—less than 9 years of continued increase would be required.

TABLE 2.—*Undeveloped water power compared with growth of generation*

[Thousands of kilowatt-hours]

Census region (1)	Increase, 1921–29 (2)	Average annual increase, 1921–29 (3)	Generation, 1937 (4)	Potential undeveloped annual output (5)	Ratio (5) to (3) (6)	Ratio (5) to (4) (7)
New England	3, 291, 519	411, 440	7, 841, 748	4, 508, 500	10. 96	0. 57
Middle Atlantic	13, 152, 912	1, 644, 114	30, 837, 046	14, 238, 900	8. 66	. 46
East North Central	14, 100, 838	1, 762, 605	28, 404, 496	3, 069, 100	1. 74	. 11
West North Central	2, 480, 969	310, 121	7, 771, 445	2, 689, 200	8. 67	. 35
Subtotal	33, 386, 238	4, 128, 280	74, 854, 735	24, 505, 700	5. 94	. 33
South Atlantic	6, 621, 729	827, 716	14, 132, 766	22, 425, 000	27. 09	1. 59
East South Central	2. 326, 125	290, 766	5, 137, 399	19, 510, 200	67. 10	3. 80
West South Central	3, 552, 870	444, 109	6, 387, 784	5, 927, 200	13. 35	. 93
Total, except Mountain and Pacific	45, 536, 962	5, 692, 121	100, 512, 684	72, 368, 100	12. 71	. 72
Mountain	2, 116, 235	264, 529	5, 777, 876	58, 844, 100	222. 45	10. 18
Pacific	6, 928, 225	866, 028	14, 759, 070	142, 164, 700	164. 16	9. 63
Total, United States	54, 581, 422	6, 822, 678	121, 049, 630	273, 376, 900	40. 07	2. 26

Data compiled by the Federal Power Commission; see *Electric Power Statistics, 1937*.

Note that the census regions shown above are not the same as the regional groups of drainage basins shown in table 1.

Water power compared with rates of growth.—A very rough idea of these relationships may be gained by comparing the average rate of growth of electric-power generation in each region with the relative quantity of water-power generation remaining to be developed. Such a comparison is set forth in table 2.

In New England, for example, the average rate of growth for the 8 years 1921–29 is shown as 411 million kilowatt-hours per year in column 3. The total output of feasible undeveloped water-power sites is estimated to be 4.5 billion kilowatt-hours per year, column 5. Continued growth of power requirements at the average rate shown in column 3 would therefore absorb the total output of the undeveloped water-power sites (column 5) or its equivalent in about 11 years.

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[7] See *Power Requirements in Electrochemical, Electrometallurgical, and Allied Industries*. Federal Power Commission, 1938.

On the other hand, in the Mountain States this simple calculation suggests that more than 200 years of continued annual load growth at the rate so far experienced would be required before the potential generation of all of this region's rich heritage of feasible undeveloped water power would feel the strain. The corresponding figure for the Pacific States is 164 years. If the growth recorded from 1932 to 1937 is used as a basis, the indicated period for the Mountain States is reduced from 222 to 90 years.

Abstracting from table 2, periods like the following appear as the lengths of time within which the equivalent of the total undeveloped and feasible water-power generation would be required if the annual growth experienced in 1921–29 should continue:

Census region:	*Years*
New England	11
Middle Atlantic	9
East North Central	2
West North Central	9
Subtotal	5.94
South Atlantic	27
East South Central	67
West South Central	13
Total except Mountain and Pacific	12.71
Mountain	222
Pacific	164
United States	40.07

Oversimplified comparisons like these cannot be viewed as definite forecasts of actual future events, but nevertheless they show convincingly that the need for such amounts of power as the remaining water-power sites can provide is by no means a matter whose consideration may be delayed until the remote future. Ratios derived from the figures given in table 2 may be high, or on the contrary they may be low.

Prices and other factors.—The actual future power needs of the several regions will, of course, be governed by many factors that may or may not follow the same course as in the 18-year period 1920–37 for which the necessary statistics are available. In many parts of the country the rate of growth may increase in the future and should perhaps be stated as a percentage increment applied to a steadily rising total. For example, in Seattle, Wash., the total electric requirements of the municipal system have doubled approximately every 7 years.[8]

Growth or decline of population, of industry, and of commerce in specific areas; discovery of raw materials or of processes now unknown; progress in the utilization of fuels or in the design of water-power structures and equipment; changes in the prices of fuel or labor, so largely responsible for the cost of fuel-generated power; changes in the price of money, so largely responsible for the cost of hydrogenerated power—these and other factors beyond the range of ordinary human prediction will govern the actual need for energy in a given region in a given future year and also the proportion of this energy that may then be most economically supplied from hydroelectric sources.

Water power compared to 1937 requirements.—Some indication of the possible future relationship between undeveloped water power and other possible sources of energy may be gained by comparing the total feasible undeveloped water-power output with the total generation of electricity for 1937. Such a comparison is abstracted as follows from column 7 of table 2, showing the ratio of total estimated undeveloped water-power output to total electric output for 1937:

New England	0.57
Middle Atlantic	.46
East North Central	.11
West North Central	.35
Subtotal	.33
South Atlantic	1.59
East South Central	3.80
West South Central	.93
Total except Pacific and Mountain	.72
Mountain	10.18
Pacific	9.63
Total, United States	2.26

It should be carefully noted that if all of the feasible undeveloped water-power sites of the principal industrial regions—New England, Middle Atlantic, East North Central, and West North Central—should be developed, the resulting total output would be only one-third of the actual output of electricity recorded in 1937 for these regions from all sources.

Warning signals in regional distribution.—Potential resources of undeveloped water power are not uniformly distributed with respect to resources of fuel, nor with respect to other natural advantages, including deposits of various raw materials.

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[8] City of Seattle, Department of Lighting: *Annual Report for the Year Ending December 31, 1936*, p. 68.

The Pacific Northwest, for example, is lacking in important fuel reserves but is supplied with water power in abundance and also with a wide variety of raw materials from forest, field, and mine.

The Pacific Southwest lacks coal but contains oil and gas and also large "reserves" of water power. In the Rocky Mountain region there are reserves both of fuel and water power in moderate abundance, together with large known resources and quite possibly larger undiscovered resources of minerals. The Central Great Plains States, substantially without power, possess large quantities of fuels—oil in the South, lignites and semibituminous coals in the North.

Throughout the Appalachian region of the South Atlantic and the Middle Atlantic States, adjacent to our eastern coast with its concentration of population and of industry, there are great reservoirs of the best coals and, in addition, very substantial quantities of undeveloped water power.

In New York, Pennsylvania, and New England the end of undeveloped water-power resources is in sight. Children now living will undoubtedly have the opportunity either to commend the present generation for its foresight in wisely guiding the development of the remaining water power in combination with other water uses and controls for the greatest good of the greatest number, or to criticize us for failure to recognize the unmistakable signals and to act with reasonable foresight on the ample information now at hand.

CHAPTER 2.—WATER POWER AND THE DRAINAGE BASINS*

Intelligent use and control of the nation's water resources requires consideration of possible water-power development in connection with all programs for river regulation. Every dam—no matter what its purpose—concentrates a head or fall which might be used in the generation of hydroelectric power. Conversely, every dam planned for water power may afford collateral benefits for one or more other purposes. Such other purposes include navigation, flood-control, irrigation, municipal water supply, pollution abatement, recreation, and wildlife conservation.

Multiple use of a given reservoir project depends, in theory, on the economic and engineering practicability of combining the several purposes. The realization of full multiple use is governed also by the breadth of vision and ability of those designing, sponsoring, and operating the project and by the financial and statutory limitations of the sponsor to provide public benefits from which no direct revenue can be obtained.

The rich possibilities of multiple-purpose development have been obscured by the failure of engineers, legislators, and executive agencies, to recognize these possibilities, and by the inability of private enterprise to take into account any benefits which would not yield direct monetary returns. Out of an estimated 53,000,000 acre-feet of reservoir storage capacity in projects of more than 20,000 acre-feet capacity in the United States in 1930, only about 4 percent of that storage was in projects designed specifically for multiple purposes; though many of the others did in fact serve more than one useful function. By 1940 approximately 53 percent of an estimated total of 143,500,000 acre-feet storage capacity will be serving multiple purposes.[1]

Credit for this increased recognition of multiple-purpose opportunities rests with public agencies; responsibility for its continuance is a challenge to their ability. Private interests, lacking any incentive to provide nonvendible benefits, cannot, in general, be expected to design or finance such undertakings for profit, no matter how large may be the total return to the public.

Practicability of Multiple Purpose Projects

The feasibility of combining hydroelectric power with other purposes in the development of water resources has been proved under many conditions. The Hudson River Regulating District, Tennessee Valley Authority, and Boulder Canyon Dam operations (described later in this discussion) are examples of effective river-regulation involving power production. The operating requirements dictated by corollary purposes may or may not permit the development of maximum power at times when it would have maximum value in supplying a particular load. Slight changes in an operating schedule or in the design, however, may permit the development of power with but slight decrease in the primary purpose benefits and a large increase in overall or total benefits. Some reservoir sites which cannot be developed economically for water power alone, may be economically developed for power in conjunction with other purposes. Likewise, a change in design to provide for power generation may render feasible a project which otherwise would not be feasible.

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*Statement by the Water Resources Committee.

[1] Estimates by W. G. Hoyt of the U. S. Geological Survey in unpublished manuscript on "Water Storage in the United States as of January 1938."

The regimen of operation for the storage and release of water to fulfill one purpose may have to be modified to meet the requirements for other purposes. Maximum production of "firm" power, for example, requires that water storage and release be related to variations in power load. For irrigation, water must be stored during periods of high flow and released during the growing season. For flood control, storage capacity must be reserved during periods when floods may occur. Where the uses of water downstream from a multiple-purpose project require a uniform flow from hour to hour, a relatively small investment in an additional dam to create a re-regulating pond below the powerhouse will increase the value of the power produced at the main plant because it will enable the output to be concentrated in the hours when the demand for power is greatest, while the re-regulating pond smooths out the varying discharge from the powerhouse.

Need for Integrated Planning

Effective planning, construction, and operation of water use and control programs in the future will require careful attention by Federal, State, and local agencies to insure a rational integration of water power with other water uses. The evolution of a comprehensive plan for integrated basin development should bring forth a series of single- and multiple-purpose projects, scheduled in an orderly sequence to meet, to the fullest extent and at the proper time, definite needs as they arise. The fact that many important streams are State boundaries or flow through more than one State emphasizes the necessity for participation and guidance by interstate or Federal agencies.

The preparation of drainage-basin plans involving water-power development has been hampered by lack of funds and by inadequacy of legislative authorization fixing responsibility for multiple-purpose water-project planning. As indicated hereinafter, basic studies, lacking in the past, of power-development programs in relation to other aspects of water use and control, and in relation to present and prospective power markets, are now being made by the Federal Power Commission on streams subject to Federal jurisdiction under conditions described in other parts of this report.

The determination and preparation of the best plan for the multiple-use development of a river system requires the highest grade of technical experience and skill. If insufficient time is provided for the assembling and analysis of the requisite basic data, and if the plan is too hastily developed, it is almost sure later to be found to be imperfect, inadequate, unsatisfactory, and wasteful.

Federal Responsibility

Pursuant to the provisions of section 1 of the River and Harbor Act approved January 21, 1927, and of House Document No. 308, Sixty-ninth Congress, first session, the War Department has made surveys of and prepared reports upon many of the more important river basins of the country as the initial step in planning for the most effective improvement of the rivers for the purposes of navigation, and with a view to making such improvements in combination with the most efficient development of the potential water power, the control of floods, and the needs of irrigation.

Under the provisions of section 4 (a) of the Federal Power Act and of sections 4 and 9 of the Flood Control Act of 1938, the Federal Power Commission has statutory authority to investigate the water-power industry and its relation to other industries and to interstate and foreign commerce; to investigate the location, capacity, development costs, and relation to markets of water-power sites on various streams of the country; and to investigate dam and reservoir projects proposed or authorized for construction primarily for flood-control purposes, with a view to conserving the power values inherent in such projects. Section 4 of the Flood Control Act of 1938 specifically provides for the installation in flood-control dams of penstocks and related facilities adapted to possible future use in the development of hydroelectric power, when approved by the Secretary of War upon the recommendation of the Chief of Engineers and the Federal Power Commission; and section 9 of the same act provides that "The sum of $1,500,000 additional is authorized to be appropriated and expended by the Federal Power Commission for carrying out any examinations and surveys provided for in this act, or any other acts of Congress, to be prosecuted by the said Federal Power Commission." The sum of $125,000 was appropriated to the Commission for expenditure during the fiscal year 1939.

Supplemental Legislation

While the Federal Power Commission clearly has authority under existing statutes to conduct systematic and continuing investigations of the water-power possibilities of any river basin or region, it is desirable that supplemental legislation be enacted prohibiting the construction of reservoirs for any purpose upon streams over which the Congress has jurisdiction until after the several purposes for which the reservoir might be useful have been properly investigated, including an investigation of potential power values by the Federal Power Commission.

Pending the passage of such additional legislation establishing a procedure by which consideration may be assured in the case of all proposed water developments, and by which power development may be planned jointly with navigation, flood control, irrigation, and other purposes, the State-Federal drainage basin committees offer a means of bringing together all related water plans for coordinated analysis by the agencies concerned. Their reports for 1937 include for each basin a statement on the power possibilities in the basin and the best plan of development as viewed by the Committee.[2] Many of those plans are inadequate because adequate studies of major uses of water in those areas have not as yet been made. Even in basins where water plans are relatively complete, the basic engineering and economic studies of the production, transmission, and marketing of power have been lacking.

Three Examples of Multiple Purpose River Regulation

Three examples may be given of successful operation of storage facilities to produce the multiple benefits for which they were designed—the Hudson River Regulating District, an agency of the State of New York; the Tennessee Valley Authority, a Federal agency; and the Boulder Canyon project of the Bureau of Reclamation.

Hudson River Regulating District[3]

River regulating districts created under New York State law are for the purpose of regulating river flow "as required by the public welfare, including public health and safety"; that is to say, to reduce floods and increase the low water flow of the rivers. The Sacandaga Reservoir of the Hudson River Regulating District is created by a dam on the Sacandaga River about 6 miles above its confluence with the Hudson. Its capacity above the low-draft line is 760,000 acre-feet, equivalent to 13.7 inches of run-off on the 1,040 square miles of controlled drainage area. Prior to its construction, elaborate studies of discharge data were made, from which was developed an operating chart designed to maintain at Spiers Falls, an important private power development on the Hudson River below, a minimum regulated flow of 3,000 cubic feet per second and a maximum regulated flow of 6,000 cubic feet per second.

A high degree of low flow regulation has been attained during the 8 years of operation, and the reservoir has at the same time operated with apparently complete effectiveness to reduce floods; no water has passed over the spillway in the 8 years of operation. But for the Sacandaga Reservoir, it is believed that the 1936 flood would have been the greatest in the history of the Hudson River. At Albany this flood reached a crest of 17.7 feet on March 19, with a discharge estimated at about 220,000 cubic feet per second. It is estimated that the Sacandaga Reservoir reduced the flood flow at Albany by about 50,000 cubic feet per second, corresponding to a decrease of about 4 feet in flood heights. The peak inflow into the Sacandaga Reservoir on March 18 was 64,400 cubic feet per second, nearly 10,000 cubic feet per second or 15 percent greater than the previously estimated "thousand year flood." Though such a great flood had not been anticipated, the deep snow cover had indicated that a large flood would doubtless occur, and accordingly, the reservoir had been almost completely depleted in January and February and during the first part of March. Between March 13 and March 21, approximately 340,000 acre-feet were impounded, but at the end of the flood period the water surface elevation was still almost 17 feet below the spillway crest.

The Sacandaga Reservoir has several times had a large effect in reducing floods on the Hudson River, but only 5 percent of its $12,000,000 cost was charged to flood control. The remaining 95 percent was paid by the power companies whose plants benefit from the regulation.

Notwithstanding the fact that its operation has benefited navigation in several ways, none of the cost of this reservoir was charged to navigation. It makes possible an early opening of the Champlain Canal by lessening the spring floods and reduces the need for closing the canal during summer and fall floods. Its operation also has increased the minimum depths in the Hudson River at the port of Albany; and because of the lowered flood heights, it has facilitated the building of docks there at a lower elevation than otherwise would have been required.

The value of the Sacandaga Reservoir in increasing the low flow of the Hudson River was thoroughly demonstrated a few months after the record flood of 1936. During August 1936 the reservoir releases constituted at least 55 percent of the flow of the Hudson River at Albany. It is believed that without such release to dilute sewage and trade wastes a condition inimical to health would have resulted. In addition, there were important benefits to navigation and to employment. From data obtained from some of the beneficiaries, it is estimated that approximately 2,500 men would have been thrown out of employment at mills along the river, which could not have remained in operation during the period of low flow had it not been for the reservoir releases.

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[2] See the series of Drainage Basin Committee reports published separately by the Government Printing Office to accompany the report on *"Drainage Basin Problems and Programs—1937 Revision."*

[3] Condensed from Edward H. Sargent, "Operation of Sacandaga Reservoir," *Civil Engineering* (November 1938), pp. 720–721.

It will be observed that although the principal continuing benefit for which this reservoir was designed (and the benefit which pays 95 percent of its cost) is maintenance of power production, nevertheless, it is operated under the law in such manner as will best regulate the flow of the Sacandaga and Hudson Rivers in the interest of the public welfare for other relevant purposes.

Tennessee Valley Authority

The Authority is empowered to construct such dams and reservoirs in the Tennessee River and its tributaries as, in conjunction with the existing dams, will provide a 9-foot channel in the river, with a water supply to maintain it, from Knoxville to the mouth; will best serve to promote navigation on the Tennessee River and its tributaries; and will control destructive flood waters in the Tennessee and Mississippi River drainage basins. It is authorized also to acquire or construct power houses, power structures, transmission lines, navigation projects, and incidental works in the Tennesse River and its tributaries, and to unite the various power installations into one or more systems by transmission lines. Any dam or reservoir under the Authority's control is to be operated so as to regulate the stream flow primarily for the purposes of promoting navigation and controlling floods. Electric energy is to be produced at any such dam so far as may be consistent with the two primary purposes, in order to avoid waste of water power.

The relation of this intended coordinate development of the Tennessee River system to programs outside of the Tennessee Basin is recognized by Congress, in that the development is ordered to be designed to benefit the Mississippi Basin also. Though not specifically recognized in the authorizing act, a similar relation exists in the field of navigation. In addition to providing facilities for navigation in the Tennessee Basin, the Tennessee Reservoir system may be operated to yield benefits to navigation in the lower Ohio and the Mississippi rivers by augmenting their dry-seasonal flows.

Incidental values created are those from the recreational use of the river and reservoir system, and from increase in fish and wild game through provision of highly favorable conditions for wildlife propagation.

Manifestly, this coordinated control is many times more complex than that of the Sacandaga Reservoir. Nevertheless, a coordinated system of reservoirs and dams has been designed and in large part built to obtain the multiple benefits just indicated. Coordinated operation is well advanced. In so extended a system, there may often be special and localized requirements (especially for navigation and for protection of construction) which should be met, and to which the operation of the whole system should be adjusted. The management of the complex system of reservoirs is supervised by a special official who takes into account all legitimate requirements for water flow or storage.

The complexity of this planned control may be best illustrated by two relatively simple operations orders and by graphs showing the results of such operations. These graphs represent conditions achieved by controlled adjustment of many conditions which, in their natural state, are almost constantly changing. Such adjustment recognizes first the requirements of navigation and flood control and, thereafter, the permissible generation of electric energy and of other requirements. (Figure 1.)

On December 10, 1937, instructions from the Chief Water Control Planning Engineer to the Superintendent of Power Operations were in the following language:

> Referring to last paragraph of Water Control Memorandum No. 18, the Guntersville Dam cofferdam has now been closed and the draw-down of Norris Reservoir to elevation 960 to provide storage space for flood control should be resumed. Also, Wheeler Reservoir should be drawn down to elevation 550, in order to provide, first, storage space for regulating flows for Pickwick Landing Dam construction operations; second, a suitable stage at Wheeler Lock to permit the United States Engineers to construct a concrete retaining wall; and third, additional depths below Wilson Dam to aid the United States Engineers in removing stone dikes before the Pickwick pool is raised.
>
> To accomplish the above, Norris release should be gradually increased, beginning today, to 15,000 cubic foot-seconds and maintained at that rate until the reservoir is lowered to elevation 960, except in case of floods. Regulated flows at Chickamauga Dam should not exceed a maximum elevation of 640 on the tailwater gage (about 69,000 cubic foot-seconds), and it is desirable that, if practicable, the flows at that point should be held below elevation 637 on the tailwater gage (about 50,000 cubic foot-seconds).
>
> Wheeler Reservoir should be lowered, beginning Monday, December 13, 1937, by gradually increasing the release to about 50,000 cubic foot-seconds, and maintaining that rate until the reservoir reaches elevation 550, after which the reservoir should be held at elevation 550, passing the flow of the river, except in case of floods. In case of floods, Pickwick Landing Dam flows should be regulated so as not to exceed headwater elevation 390 (about 160,000 cubic foot-seconds) until December 15. After December 15 flows at Pickwick Landing Dam should be regulated so as not to exceed tailwater elevation 372 (about 115,000 cubic foot-seconds).

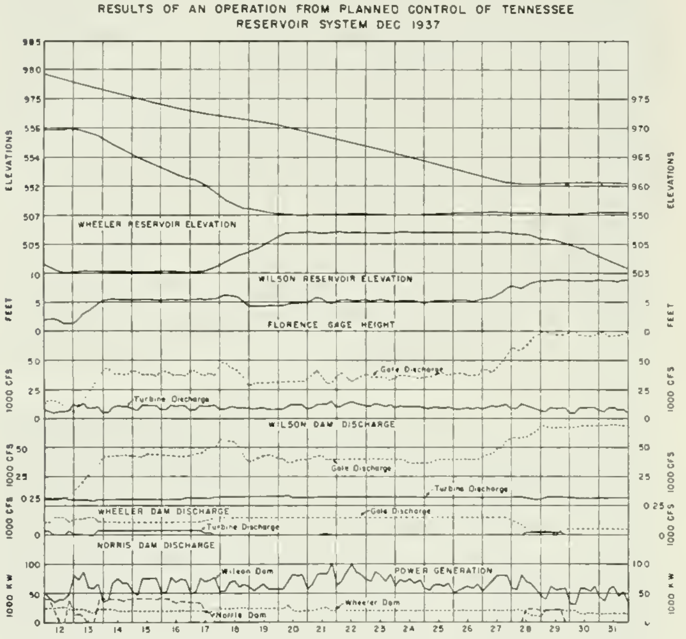
The accompanying chart shows the results of operation under the above order.

On May 21, 1938, the instructions were in the following language:

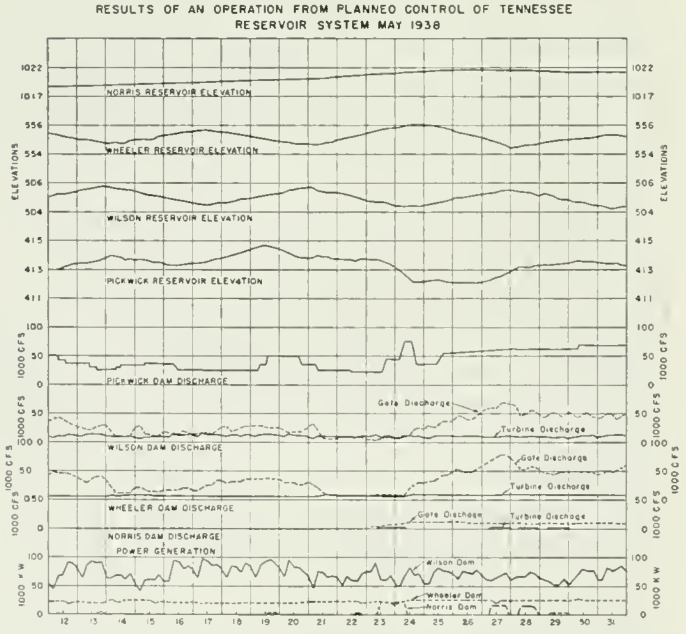
> The United States Army Engineers require a Pickwick Dam Release of 75,000 cubic foot-seconds for about 7 hours on Tuesday, May 24, in connection with navigation tests. Also the Ingalls Iron Works Co. plans to launch a barge at Decatur on

Wednesday, May 25, and desires a stage of 21.6 at Decatur for that purpose.

To accomplish the above, Wheeler Reservoir should be filled gradually, beginning today, to reach about elevation 556.0 by 8 a. m., Tuesday, May 24, held steady at that stage until 6 p. m., Wednesday, May 25, and then lowered gradually to reach elevation 554.5 at midnight, Friday, May 27, after which the previously outlined malaria control fluctuation schedule should be followed.



(From Monthly Chart No. 10 of *T. V. A. Reservoir Stages and Discharges,* December 1937)



(From Monthly Chart No. 19 of *T. V. A. Reservoir Stages and Discharges,* May 1938)

FIGURE 1.—Graphs Showing Results of Planned Control of T. V. A. Reservoirs.

Wilson Reservoir should continue on the regular malaria fluctuation schedule. Releases at Pickwick Dam should be regulated to hold the reservoir under elevation 414.0 over the week end and to lower it to about elevation 413.5 by 4 p. m., Monday, May 23, after which the release should be gradually increased to reach 75,000 cubic foot-seconds by about 9 a. m., Tuesday, May 24. The 75,000 cubic foot-seconds release should be continued until the completion of the navigation test requiring that flow during the afternoon Tuesday, and then gradually reduced to not less than 20,000 cubic foot-seconds. The release should then be regulated to restore the reservoir water surface to the regular malaria control fluctuation schedule as soon as practicable.

The accompanying chart shows plainly the results of operation under the above order.

The foregoing exhibits show some of the technical problems involved in operating a system designed and operated primarily for flood control and navigation benefits. The Authority has developed a procedure for routing flows of water through the Tennessee River system in a manner somewhat comparable to the dispatching of trains over a great railway system. As the number of completed dams increases, the problem of coordinated operation will become more complex, and at the same time, the opportunities for utilizing the existing reservoir storage will improve. For example, the completion of the Gilbertsville project near the mouth of the Tennessee will make possible more flexible operation of the upstream reservoirs.

Boulder Canyon Dam

The Boulder Canyon Project Act of December 21, 1928, authorized the construction by the Bureau of Reclamation, Department of the Interior, of Boulder Dam, which was completed on the Colorado River about 26 miles southeast of Las Vegas, Nevada, in May 1935. With the construction of Boulder Dam, Lake Mead, a reservoir of unequalled size, was created in the arid valleys and canyons extending 115 miles up the Colorado River. Lake Mead has a capacity of 30,500,000 acre-feet of water, an amount slightly in excess of twice the annual average flow of the river at Boulder Dam.

Boulder Dam has provided a large measure of control of the main stem of the Colorado River and has changed the character of that erratic and once dangerous stream for more than 500 miles of its lower course. Motivation for construction of Boulder Dam was found in needs arising in two localities, one adjacent to the lower river and the other the southern California coastal plain, 250 miles west. Arid valleys along the lower river, which had been made productive by irrigation, were endangered by the uncontrolled river which threatened them annually with floods and with water shortages. Rapid urban and industrial development on the semiarid Coastal Plain in the vicinity of Los Angeles forecast a requirement for an additional water supply and provided a prospective outlet for a large block of hydroelectric power.

All the needs in the lower basin of the Colorado River and adjacent area were considered in the design of the project. It was determined that to fill these needs a dam and reservoir of unprecedented sizes would be required. Extraordinary physical conditions above the dam site in Black Canyon, in an area which was virtually uninhabited, made it both feasible and practical to construct a Boulder Dam to a height of 726.4 feet, thereby creating a reservoir which would flood 146,500 acres. Boulder Dam has improved the navigation of the Colorado River, although navigation of the stream is not now and probably never will be important, except perhaps by pleasure craft in the reservoir sections. It has provided a large measure of control of floods; it has insured a regular and reliable irrigation water supply for irrigated areas now developed and aggregating more than 1 million acres and for areas equally extensive which may be developed in the future; it has provided a source of supplemental domestic water for the metropolitan district surrounding Los Angeles; and it has made it possible to generate at the Boulder Power Plant, at Boulder Dam, 1,835,000 horsepower of electric energy. In addition to these functions, Lake Mead also serves as a wild waterfowl refuge; as a unique recreational center of great and growing importance; and as a catchment basin for the silt carried by the Colorado River in its Grand Canyon section.

This long list of purposes and services includes some of great social and economic importance and others of less but still notable worth. While neither in the authorization of the project nor in a program of operation for the project was the generation of power the primary purpose of Boulder Dam, the plan for financing Boulder Dam and power plant depends upon power revenues, together with a relatively small additional revenue from sale of water for domestic use, to return in 50 years with interest at 4 percent the entire cost of these structures, estimated at $130,000,000, except for $25,000,000 allocated to flood control, repayment of which may be deferred beyond the 50-year period. The contracts actually executed for the lease of power privileges, it is anticipated, not only will repay these construction costs with interest in the required time, but also will return a surplus from which the amount allocated to flood control will be repaid with interest and from which comparatively large payments will be made annually to the States of Arizona and Nevada in lieu of taxes.

The social and economic values of the regulation of the river are illustrated by the facts that in 1934, before Boulder Dam was completed, the flow of the Colorado River was so low during the late summer and fall that crop losses in the Imperial Valley of southern California alone were estimated at more than $10,000,000, and that in the early summer of 1935, a few months after storage in Lake Mead was begun, Boulder Dam halted a flood in the Colorado River which very likely would have breached the levees protecting the Imperial Valley, since these levees were in poor condition as a result of extended drought.

An indication of the importance of the provision of a supplemental domestic water supply to the cities of the southern California Coastal Plain is found in the fact that 13 of these communities organized a metropolitan water district and bonded themselves to the extent of $220,000,000 for the construction of an aqueduct reaching from the Colorado River to the Coastal Plain. This aqueduct is now being completed.

The importance of Lake Mead as a wild waterfowl refuge and as a sport fishing area, and the importance of the lake for recreational purposes only now are being realized. Prior to the commencement of the construction of Boulder Dam, only a few intrepid explorers had threaded the canyons now flooded by Lake Mead. At present, more than 100 commercial and pleasure craft ply the waters of the lake, and the trip up the lake from the dam through the spectacular Boulder, Travertine, Iceberg, and into the lower end of the Grand Canyon is made by hundreds of people a month. Last year, approximately half a million persons visited Boulder Dam and more than half this number took some part in the recreational activities, which include bathing, boating, fishing, and sightseeing on Lake Mead. One of the major recreational areas of the West already has developed at the dam. It ranks, when judged by the number of visitors, with Yosemite and Yellowstone National Parks.

The records of the Hudson River Regulating District, the Tennessee Valley Authority, and the Boulder Canyon Project demonstrate the practicability of operating multiple-purpose reservoir systems so as to yield substantial benefits of many types including hydroelectric power. A major objective in conservation of the Nation's power and water resources is to insure that such combined developments will be designed and operated to produce maximum public benefits wherever the physical and economic conditions render them feasible.

PART TWO—SECTION III
SUBSTITUTE FUELS AND MARGINAL ENERGY RESOURCES

CHAPTER 1.—THE SCIENTIFIC OUTLOOK

By H. C. Dickinson*

Science, in the broad sense of the term, has been instrumental in the development and widespread use of sources of energy rather than in their discovery. The invention of sails, windmills, and water wheels made power available from wind and water. The invention of the steam engine led to the use of coal as a source of mechanical power. The internal-combustion engine created a demand for liquid and gaseous fuels after they were already available, and countless industrial processes still further extended the use of these fuels. Applications of electricity created enormous new demands for new supplies of energy which could be converted into electric power.

Only recently have science and technology contributed much to the development of new energy sources or even to the conservation of those we have already developed. However, as the demands for energy increase and the readily available supplies decline, more and more scientific effort is being devoted to raising the efficiency with which energy sources are utilized and to the discovery of new sources. The steam power plant now produces several times the useful energy from coal that it did 50 years ago. Likewise liquid and gaseous fuels are being used with increasing efficiency. New scientific methods have led to the location of new petroleum reserves, and improved methods of recovery have increased the percentages of oil which can be recovered from the wells.

Of perhaps greater importance to the future, however, are the new developments in the transformation of fuels or hydrocarbons from one form to another. Present uses call for fuels in all forms, solid, liquid, and gaseous. For many purposes only liquid or gaseous fuels can be used efficiently. Since the potential sources of these fuels are much more limited than those of the solid fuels, particularly coal, we might be facing a shortage of liquid fuels even while there remained a large supply of coal. Fortunately, thanks to scientific developments, this will not be the case. Liquid and gaseous fuels can now be produced at will from coal. The comparative ease with which almost any combination of hydrogen and carbon can be transformed into almost any other combination which may be wanted as fuel justifies the belief that so long as hydrocarbons are readily available, fuels of all three sorts will be available at will.

Other potential sources of liquid fuels are oil shales and the residues of oil left in the oil-bearing strata from which petroleum has been produced. It would be futile to attempt at this time to estimate the probable future productive efficiency with which liquid fuels may be recovered from these sources as compared with coal. Considering only present technique, it is probable that coal will provide liquid fuels at lower cost than shales or oil-bearing sands. But development of new methods of recovery and technique in treatment of the raw materials may well change this picture entirely before we need have recourse to these supplementary sources of liquid fuel.

It appears, therefore, that scientific and technical developments will tend more and more toward the conservation of energy resources and the discovery of new sources as time goes on. In fact, we may even be justified in ceasing to be disturbed over the diminishing energy resources of the world, in our confidence that scientific developments will meet the needs of the future before they become acute.

However, even if there should never be a shortage of available energy in suitable form, one other factor should not be overlooked. That is the ever-increasing cost in men's efforts required to make energy sources available. Naturally, at first men have skimmed the cream, so to speak. Easily mined coal, oil, natural gas, water power that could be developed at little expense, all have supplied energy with little effort. This generous supply of readily available energy has played a large part in the rapid industrial growth of America. Even with the extension of science in the field of energy production the cost of energy in terms of men's efforts is likely to increase as the supplies diminish, and will do so unless technical developments sufficiently increase the efficiency of men's efforts.

Let us examine some of the present, prospective energy sources which may possibly be tapped in the future if not now, and see what part science may play in their utilization. In doing so, we shall try not to compete with Jules Vernes or H. G. Wells along visionary lines. From the point of view of the physical sciences, some things are known to be impossible because they call for the violation of well established laws of nature. Other things one may suspect are impossible for like reasons, though one may not be able to show clearly why this is the case. Still other things, while not impossible from the theoretical standpoint, may be unobtainable practically because of insurmountable difficulties.

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Agricultural Products

Agricultural products, beside serving as foods, afford sources of energy in the form of fuels. From the practical standpoint, all fuels are derived ultimately from vegetation. The process of photosynthesis whereby water and carbon dioxide from the air are split up and recombined to form hydrocarbons or other compounds containing them, accounts for all the fuels occurring in nature, such as coal, oil, natural gas, shale oil, peat, wood, and all combustible products of vegetable origin. Most of these are discussed elsewhere in this general report, but one phase of the problem may merit further attention here.

Photosynthesis, of course, depends on radiation from the sun as a source of energy required to separate hydrogen from the oxygen in water and carbon from the oxygen in carbon dioxide, thus permitting their recombination into hydrocarbons from which the energy can be recovered by ordinary combustion. The process as it occurs in nature makes use of only the most minute fraction of the solar radiation. In other words, the natural process is almost unbelievably inefficient. The solar radiation falling on the United States has been estimated at some 9,000 billion horsepower. To put this in another form, to supply the amount of energy received from the sun would require burning some 15 million tons of coal per minute. The entire stored up fuel reserves of the United States, coal, oil, and gas, if burned in 1 year, would not supply as much energy as is received from the sun during that year. Yet these reserves have been many millions of years in accumulating. Only a part of the sun's radiant energy is to be found in those wave lengths which are effective in the natural process of photosynthesis. Furthermore, only a very small part of this is used in ordinary processes of growth. What we would emphasize here is merely the fact that the natural process utilizes so very little of the available solar energy that there is room for revolutionary improvement if this process could be replaced by a similar or better one which could be kept under scientific control.

Briefly, what happens in photosynthesis is that radiation from the sun falls on a substance, chlorophyl, produced by plants. The presence of this substance permits the radiant energy to remove hydrogen and carbon from their combinations with oxygen and re-form them into hydrocarbons or substances containing them, which can combine again with oxygen releasing energy by combustion. There is no obvious reason why such a reaction can not be made vastly more efficient if the raw materials, particularly carbon dioxide, are supplied in optimum amounts. In the natural processes of plant growth, the latter is available only in minute quantities, thus setting a limit to the amount of radiant energy that can be utilized.

Conceivably, such an accelerated process of photosynthesis might result in an enormously accelerated process of plant growth or it might become a purely chemical process without the presence of living matter. Steps have already been made toward the great stimulation of plant growth along the line here suggested. We know of no steps as yet along the second line. There may be reasons why such are impossible.

The subject of solar energy utilization through photosynthesis is to be given careful study, since a fund of more than a half million dollars has been donated to the Massachusetts Institute of Technology for studies in this field.

Atomic Energy

During the past few decades, as men have learned more and more about the enormous amount of energy tied up in the structure of matter, there has been considerable speculation as to whether such energy can ever be released for the practical use of society. The conversion factor in the equation for the equivalence between mass and energy is the square of the velocity of light, which means that 1 gram of energy is equivalent to 10^{21} ergs, or about 25 million kilowatt-hours. Thus 1 pound of fuel, if the energy equivalent of its mass could be released, would be sufficient to run a 1,000 horsepower motor from the birth of Christ to 6 months after the birth of George Washington.

Of course, it is not possible to convert all mass to energy, but when hydrogen is converted into helium, four atoms of mass 1.008 each are transformed into one helium atom of mass four with the result that 1 percent of the original mass is converted into energy. The energy from the conversion of 1 pound of hydrogen to helium would thus run our 1,000-horsepower motor about 15 years, so that any process of unlocking the storehouse of atomic energy need not be at all efficient in order to take care of all of our conceivable needs. In all the laboratory experiments so far, however, only one atom out of countless billions is actually "transmuted," so that the energy required to make the experiment is millions of times the energy released.

It must also be considered that if a means were discovered to release atomic energy in large amounts without a method of controlling the process, the discovery would probably be recorded by the inhabitants of other solar systems as the formation of a new star.

For the present, therefore, the utilization of atomic energy is to be classed as possible, but unattainable practically.

Solar Radiation

Aside from the use of solar radiation through photosynthesis, there always remain the possibilities of more direct utilization of it. This is the source of the mechanical energy which we derive from wind and waterfalls. It has been used experimentally by Dr. Abbot, director of the Smithsonian Institution, as a source of power by means of a steam engine. The direct application of solar energy to power production offers both theoretical and practical difficulties which seem to preclude its practical use except, possibly, under very unusual conditions. We shall, therefore, simply class this as an unpromising source of energy for practical purposes, at least so long as other sources are available.

Another possible source of power from solar energy is suggested by the photo-electric cell. Some substances have the property of transforming solar radiation directly into electric current. The process as now known has an extremely low efficiency, not at all promising as a source of practical electric power. We mention the subject here, however, because there seems to be no underlying reason why the efficiency of the process should be as low as it is, no reason, in fact, why the transformation of direct radiation into electric current might not be made efficient enough for practical utilization.

This source of energy we must look upon, therefore, as remotely possible of practical application, because we know, as yet, of no fundamental reason why it can not be made much more efficient than at present.

The Earth Itself

Some rather limited sources of energy are available from the structure of the earth itself. There are marked differences of temperature between the surface and the bottom of the sea, and likewise there are, in some locations, great differences between the surface and the subterranean temperatures. Such temperature differences can be utilized, in theory at least, as a source of mechanical power, or as a direct source of electric current, as by the use of thermocouples. The sea water differences have been the subject of extensive experiments by Georges Claude, but with rather disastrous results. The heat of the earth is utilized in a practical way in some locations, such as at Helsingfors, Finland, where use is made of steam coming from underground. Other uses of steam supplies from underground have occurred, but, so far as we know, only where natural causes have made them available.

We must conclude that such sources offer no worthwhile promise of energy except in limited areas and under very unusual conditions. The limitations, both theoretical and practical, are such that these sources are not worth including among the available energy resources. Much the same thing may be said of the tides, another terrestrial source of power. Only under very special and limited conditions, if at all, can men hope greatly to supplement the available energy from this source.

Summarizing the prospective energy resources of the United States and the world as a whole, from the point of view of scientific and technical development, the picture is gratifying. Solid, liquid, and gaseous fuels will almost certainly be available from stored-up supplies for several thousands of years at the present rate of consumption. The cost of these fuels, in terms of human effort, may increase, but again, this increase may be offset by increases in the efficiency with which we utilize man power.

Before the stored resources of fuels are exhausted we may confidently expect that the efficiency with which we can use the energy radiated from the sun will increase so that there will be no acute energy shortage. Solar energy may be utilized through photosynthesis to accelerate plant growth, by some such process applied directly to the production of hydrocarbons, or possibly through a direct transformation of solar energy into electric current. Once these processes are established, the production of energy will become independent of stored resources. It will be definitely renewable.

Minor energy supplies which might be had from differences of temperature on the earth or from tidal forces are not worth giving general consideration. Their utilization will not be necessary, and they will be used only where very special local conditions permit it.

We believe, therefore, that the United States, at least, will not encounter a shortage of its energy supplies within any predictable period of time. If its oil and gas resources are exhausted long before those of other nations, the United States may face some handicap, in that the production cost of its energy supply may be higher than in nations which have conserved their oil supplies.

CHAPTER 2.—FOREIGN EXPERIENCE IN THE USE OF SUBSTITUTE AND SYNTHETIC MOTOR FUELS

By Paul L. Hopper*

The United States Fortunately Situated as Regards Liquid Fuels

Many years of experience with a rapidly growing oil industry, ever improving its products and all the while disposing of them at lower and lower prices to the consumer, has accustomed us in the United States to take for granted an adequate supply of good motor fuel. Knowing that gasoline is but one of the derivatives of petroleum, we assume too, that there must be produced sufficient Diesel oil, fuel oil, kerosene, and lubricants to meet the ever mounting needs of industry. Many foreign countries are less fortunately situated than the United States, for deposits of petroleum are not equitably distributed throughout the world.

Of the larger industrialized nations, only the United States and the Union of Soviet Socialist Republics are in a position to obtain their requirements of petroleum from within their own boundaries. Neither they, nor the principal petroleum supplying countries—Venezuela, Iran, Netherlands Indies, Rumania, Mexico, Iraq, Colombia, Peru, Trinidad, and Bahrien Island—for the present at least, evince more than an academic interest in the development of nonpetroleum liquid fuels. All of the remaining countries of the world are concerned with the problem of obtaining adequate supplies of liquid fuels.

Until the last few years nations lacking sufficient petroleum were content to import their needs. Alternative sources of supply assured competitive prices in world markets; liquefaction of coal was in the experimental stage, and there was little inclination to try out substitute motor fuels. Then came the world-wide depression and, in its wake, the accelerated demand for national self-sufficiency in most countries. Unfavorable trade balances have sought correction in exchange control, barter arrangements, import quotas, higher tariffs and bilateral trade agreements, all of which tend to restrict the free flow of petroleum and its products in world commerce. At the same time, consumption of petroleum has steadily risen; the demand for motor cars, industry, and shipping has grown progressively from year to year, and provision for national defense has become the problem of paramount concern of nations.

Synthetic and Substitute Fuels Differentiated

Any appraisal of the manufacture and use of synthetic and substitute fuels aside from shale oils must be reflected largely in German experience. In that country were developed the basic processes for the liquefaction of coal; there alcohol, benzol, and methanol early came into use as motor fuel; and, in Germany, the utilization of miscellaneous substitute fuels first attained significant proportions. For the purposes of this study, fuels having essentially the same composition of hydrocarbons as gasoline, kerosene, gas oil, Diesel oil, and fuel oil are considered "synthetic fuels." For the most part, they are obtained from the liquefaction of coal or distillation of oil shale and may be used interchangeably with the derivatives of petroleum. Ethyl alcohol, methanol, gases, vegetable oils, wood, charcoal, coal, coke, coal dust, etc., are termed "substitute fuels." Satisfactory utilization of these frequently requires adjustments of existing engines and even specially built power plants. As this study is concerned primarily with motor fuels, other fuels are referred to only for the purpose of explaining more clearly the position of motor fuels. Interest at present centers principally around synthetic fuels due to their ready adaptability.

Synthetic Fuels

Liquefaction of Coal

Essentially, liquefaction of coal consists in breaking up the heavy coal molecules and with the aid of added hydrogen, reforming them into light hydrocarbons like those composing petroleum. Additional hydrogen is necessary to the reaction because the ratio of carbon to hydrogen in coal, around 15 to 16 to 1, must be reduced to about 7 to 1, the proportion of carbon to hydrogen in petroleum. The reaction may be accomplished as a continuous process by hydrogenation, by the synthesis of water gas or, indirectly, from coal tar obtained from the manufacture of gas and coke.

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AUTHOR'S NOTE.—Foreign governments have shrouded developments in the synthetic fuels industry with military secrecy and have decreed severe penalties for those divulging unauthorized information. Knowledge is incomplete concerning the type and efficiency of processes used in new plants being erected in Germany, and only meager information is available dealing with yields of products and operating costs in France, Italy, and Japan. Fortunately, a less apprehensive attitude prevailing in England has permitted the release of reports from which reliable inferences may be drawn as to the outlook for the liquefaction of coal. Foreign office reports of the Departments of State and Commerce and works of well-known fuel specialists were freely consulted in the preparation of this study.

Although coal was hydrogenated in the laboratory by Berthelot in 1869, Dr. Frederich Bergius, German Nobel Prize winner in chemistry in 1932, is generally credited with first demonstrating the feasibility of large scale hydrogenation. After some 14 or 15 years of basic research, Bergius in 1927 transferred the results of his experiments to the I. G. Farbenindustrie, the great German chemical trust, which working independently of Bergius, had discovered certain nonpoisoning catalysts and divided hydrogenation into liquid and vapor phases, both significant contributions to the development of coal liquefaction.

In the Bergius-I. G. Farbenindustrie process of hydrogenation, a paste, formed of approximately equal parts of clean pulverized coal and heavy petroleum or coal oil, is placed in conversion chambers maintained at 250–275 atmospheres; here the coal-oil paste comes in contact with hydrogen, and a catalyst is added to speed up the reaction, liquefaction resulting at 450°–500° C. Generally, gasoline, an intermediate oil, and a heavy oil are formed. The intermediate oil is either disposed of as a Diesel oil or vaporized and mixed with hydrogen and subjected again to hydrogenation in the presence of a catalyst. The residual intermediate oil may be sold as fuel for low speed Diesel engines, or thrown in with the heavy oil which, mixed with a batch of pulverized coal, is returned to serve as a new charge for the hydrogenation plant. Early plants obtained from a metric ton of coal processed approximately 54 gallons of gasoline, 60 gallons of Diesel oil, 22 gallons of fuel oil, 18 gallons of lubricants, 462 pounds of gas, and 662 pounds of pitch. Improved equipment and technique now enables the recovery of over 200 gallons of gasoline.

The foregoing description of the Bergius-I. G. process assumes the use of coal or lignite. Hydrogenation is also applicable to tar and petroleum; the latter, if subjected to hydrogenation, may be practically all converted into motor fuel. Moreover, not only liquid fuels but a full range of synthetic petroleum products, including lubricants and solid derivatives, can be obtained from the liquefaction of coal.

Bergius-I. G. process chief factor in German synthetic fuels industry.—Almost immediately after acquiring the Bergius patents, I. G. Farbenindustrie commenced the erection of the first unit of their Leuna works at Merseberg. Construction of this plant, scheduled to produce 350,000 barrels annually of gasoline from lignite, launched hydrogenation on a commercial scale. Failure to overcome certain technical difficulties necessitated the use of low temperature tar instead of lignite until 1931. Since then progress has been noteworthy. The Leuna works has been enlarged to a capacity of approximately 3,000,000 barrels of gasoline a year. Three additional plants, each having an annual potential output of around 1,275,000 barrels of gasoline, have been built by the Braunkohlen Benzin, A. G. This concern, set up by I. G. Farbenindustrie and several lignite mining companies, operates plants at Bohklen, Schivarheide, and Magdeburg. The Braunkohlen Benzin A. G. group, including the plant under construction at Zeitz, is expected to produce around 3,600,000 barrels of gasoline in 1938.

It is reported that soon the Union Rheinische Braunkohlen Kraftstoff, A. G., will build a new plant to hydrogenate lignite near Cologne, and that at Politz a similar plant is to be constructed by the Hydrierwerke Politz, A. G. Approximately 90 percent of Germany's synthetic gasoline was produced by the Bergius-I. G. method of hydrogenation in 1937. Total output is stated to have been from 6,800,000 to 7,000,000 barrels of gasoline, 870,000 barrels of Diesel oil, and 2,130,000 barrels of fuel oil from the liquefaction of coal in that year.

Liquefaction of coal also accomplished by synthesis of water gas.—Ranking second in importance to the Bergius-I. G. process is the Fischer-Tropsch method of producing synthetic fuels, which may in the future outdistance its older rival. German experience would indicate that Fischer-Tropsch units, smaller than plants employing the Bergius-I. G. process, can be operated about as economically as the latter; that these small units, properly scattered and effectively camouflaged, are relatively secure from aerial attack. Moreover, the gas-synthesis process may be used advantageously in conjunction with the high-temperature carbonization of coal. Called hydrogenation, it is really a form of polymerization. Water gas, made from coal or coke, is converted into a "synthesis" gas composed of hydrogen, carbon monoxide, and carbon dioxide, respectively, in the approximate proportion of 56, 28, and 16 percent by volume. The gas thus formed is freed of sulphur and in the presence of a suitable catalyst, generally finely divided nickle or cobalt, passed into reaction chambers at atmospheric pressure where synthesis occurs at 180°–210° C. Cooled by water, the heavy distillate vapors readily condense. The light fractions remaining in the gas are absorbed in high-grade coal or activated charcoal. Upon application of heat, light distillate vapors are formed; on cooling, these condense. It is said that current operations enable a metric ton of coal to be converted into 62 percent gasoline, 26 percent Diesel oil, 10 percent gas, and 2 percent paraffin. (Coal is presumably free of ash and water.)

Drs. Franz Fischer and H. Tropsch, originators of the process bearing their names, commenced work around 1925, but practically no commercial exploitation of this method of manufacturing synthetic petroleum products occurred until 1934. In that year, Ruhrchemie, A. G., owner of the process but operating through Ruhr Benzin, A. G., began construction of three plants in Rhenish Westphalia. It is reported that another plant has recently been completed at Bradenburg and that three additional plants are scheduled for early erection. Aggregate annual output of gasoline in Germany by the Fischer-Tropsch process is expected to account for a substantial portion of the total production of synthetic fuels during the next few years.

Other means of converting coal to liquid fuels, in a sense about midway between hydrogenation and carbonization, are being developed in Germany. A plant was recently set up in the Ruhr by Ruhrul G. m. b. H. Battrop to work the Pott-Broche process. By it coal or lignite is treated with solvents, generally tetraline, phenol, or phenolene, yielding a pitch which is converted into synthetic fuels. This process, as well as the Uhde method for liquefying coal, recently reported abandoned, produces principally heavy oil. This heavy oil in turn must be hydrogenated if a substantial quantity of gasoline is to be recovered.

Gas and coke plants supply substitute fuels and materials for synthetic fuel manufacture.—Liquefaction of coal by hydrogenation and variations of that method have resulted in a reappraisal of the carbonization industries as a source of liquid fuels. In this field Germany has not monopolized achievement, as competitors, particularly Great Britain, have made notable progress.

Coal, if heated out of contact with air to 1,000°–1,200° C. yields gas, useful for illumination and fuel, metallurgical coke and a residue of tar. Benzol is obtained by scrubbing the gas, while the tar, after distillation to recover additional benzol, may be utilized as heavy boiler fuel or further refined to yield creosote. Creosote can be mixed with pulverized coal to form the paste serving as a charge for hydrogenation.

If coal is carbonized at lower temperatures, say 400°–800° C., there is obtained as the principal product a semi-coke, highly esteemed as domestic fuel, gas, and about twice as much tar as with high-temperature carbonization. The gas may be stripped of its gasoline content. Gasoline and fuel oil are obtained if the tar is distilled or, the tar may be subjected to hydrogenation and converted into 80–90 percent of its weight in motor fuel.

Gas, creosote, and low-temperature tar resulting from the carbonization of coal are raw materials which may be processed to yield motor fuels. Benzol, used as a fuel blend, creosote and illuminating gas when utilized as substitute motor fuels and coke where used to produce gas in an engine propellant are referred to elsewhere in this study.

Carbonization industries coordinated with coal liquefaction in Germany.—Gas and coke plants in Germany have been instructed to install the latest carbonization plant in order to effect the maximum recovery of benzol and tar. Improved processes for both high and low temperature carbonization of coal are attributed to such well-known designers as Bubiag-Didier, Koppers, and Lurgi. Although the figures seem high, it is said that from 12–15 tons of tar are now obtained from 100 tons of coal; of special interest is the tar from the Lurgi process developed with the aid of Krupps. It may be run through a roller press at 2,500 atmospheres to form briquettes for domestic use or converted into synthetic fuels by hydrogenation.

Expansion of coal carbonization is planned in Germany, through the erection of several plants in the Ruhr. These are intended to work in close conjunction with the Bergius-I. G. and Fischer-Tropsch plants producing synthetic fuels in that region.

Hydrogenation developed chiefly by Imperial Chemical Industries, Ltd., in England.—British interest in Bergius' work probably dates from the beginning of the fuel research station's experiments in 1923. Shortly after, the British Bergius Syndicate was formed to investigate the adaptability of the process to British coals. By 1927 Imperial Chemical Industries, Ltd., had acquired financial control of the syndicate and had commenced experimental work at Billingham, where a small plant to treat 10 tons of coal daily was set up in 1929. In 1933 assured of a preference of 13.7 cents per gallon over imported gasoline, Imperial Chemical Industries, Ltd., began construction of a plant, completed in 1935, to have an annual output of 1,300,000 barrels of gasoline of which 860,000 barrels was to be made from coal, 350,000 barrels from creosote oil and 90,000 barrels from coal tar. So far actual production has fallen short of that figure, being 593,000 barrels in 1935, 950,000 barrels in 1936 and estimated at approximately 1,115,000 barrels for 1937.

Application of the Bergius-I. G. process, coupled with improvements claimed by Imperial Chemicals Industries, Ltd., to British coals, indicates that 1 to 1½ tons of coal as raw material plus 3 to 3½ tons of coal as fuel are required to produce approximately 8½ barrels of gasoline. It is said that the yield of gasoline is in excess of 60 percent of the weight of the coal used as a charge and that tars and creosote may be converted into 80–90 percent of their weight in gasoline. It is possible to produce 75 octane gasoline.

There has been little effort as yet to exploit the Fischer-Tropsch process in the British Isles. It is reported, however, that Low Temperature Carbonization, Ltd., has under consideration the erection of a plant using this method to operate in conjunction with one of their "Coalite" plants and that the Powell Duffryn Associated Collieries, Ltd., is investigating the process. A process, similar but claimed to be superior, to the Fischer-Tropsch method of liquefying coal has been developed by Synthetic Oils, Ltd. A trial is being accorded this process at a 200 ton per annum plant at Messrs. Bairds Colliery at Bedlay near Cambridge. The Synthetic Oils, Ltd., method is reported to achieve substantial economies in operation as compared with the Fischer-Tropsch process and to produce a better gasoline, an excellent Diesel oil, and larger yields of high grade lubricating oil.

British interested in low temperature carbonization.—Some 200 low temperature carbonization processes have been proposed in Britain, but only a few have achieved commercial exploitation. These differ in type, mainly, as the retort is made of brick or steel, whether it is stationary or revolving, if vertical or horizontal, how heated—internally or externally, and whether the process is intermittent or continuous.

Typical is the "Coalite" process developed by Low Temperature Carbonization, Ltd., reported to account for the bulk of coal currently carbonized at low temperatures in Great Britain. Five plants are using the process, and some 5,000 distributors are said to stock "Coalite"—low temperature coke. Much of the gasoline initially recovered is sold to the Royal Air Force, while the remainder is disposed of as "Carless Coalene" to motorists. The Diesel oil distilled from tar is satisfactory if treated with certain "dopes" to improve its cetane rating. An increasing number of industrial chemicals—flotation oils, tar acids, dipping oils, sprays, etc.—are being obtained from low-temperature tar.

Fifteen low-temperature carbonization plants worked on a commercial or near commercial scale during 1936. The average yield of principal products per long ton of coal was as follows: semicoke, 4/5 ton, tar, 20.3 gallons, gas, 31.2 therms, and crude light fraction from gas, 3.5 gallons. Total output of these amounted to, respectively, 287,000 tons of semicoke, 181,000 barrels of tar, 2,043,000 M cubic feet of gas, and crude gasoline 31,000 barrels.

Gas and coke plants in the British Isles subjected some 39,100,000 long tons of coal to high temperature carbonization during 1936. In addition to gas and coke and byproduct benzol, approximately 2.286,000 barrels of creosote were recovered from tar.

Manufacture of synthetic fuels not far advanced in France.—Coal liquefaction appears not to have progressed far beyond the experimental stage in France, but measures taken by the Government in recent years such as the 1936 law, levying a tax on imports of crude petroleum and refined products to promote production of synthetic fuels, are expected to encourage the development of hydrogenation in that country. For some years 2 small hydrogenation plants have been in operation; that at Bethune employing the Vallette process, the other at Lievin using the Audibert process. Taken together, their annual output of gasoline is about 85,000 barrels.

The Courrieres-Kuhlman Co. is reported to be building, or to have in operation, a Fischer-Tropsch plant at the mouth of the Rhone River with an annual capacity of 215,000 barrels of gasoline. Three other hydrogenation plants, each having an approximate annual output of 510,000 barrels of synthetic fuels, are reported to be planned for erection at Gardanne, Decozsville and near the lignite deposits at Landes. Each plant is to employ a different process; one, the Vallette, another, the Audibert and last, the hydro-patents process.

Synthetic motor fuels only of academic interest in Union of Soviet Socialist Republics.—The question of producing synthetic fuels in the Union of Soviet Socialist Republics has received but casual attention in connection with the continuous round of scientific investigation of the nation's vast resources. "Industrialization" reports that 3½ tons of peat have been converted into 1 ton of semicoke suitable for use in gas generators driving trucks, gas adaptable as fuel for buses, and motor fuel satisfactory for passenger cars. "Sapronel" coals may be processed so as to yield of their weight 40 percent kerosene and 25 percent of 67 octane gasoline according to the same journal.

Italy encourages manufacture of liquid fuels from domestic materials.—Being largely dependent upon imports of coal, it has not been feasible for Italy to develop a coal liquefaction industry. Nevertheless, the Government, by a diversity of measures, seeks to utilize hydrogenation to render Italy less dependent upon foreign supplies of liquid fuels.

Bounties are paid on the production of oils from bituminous rock, coal, lignite, peat, and crude petroleum of Italian origin, as well as on oil from Italian concessions in Albania. Manufacturers of synthetic fuels from domestic materials are permitted to import needed machinery and equipment duty free if not produced in Italy. These concerns, if agreeable to relinquishing financial control to the Government, may obtain financial assistance from the Ministries of Finance and Corporations.

Most notable of Italian hydrogenation projects is the 400,000,000 lire company known as Azienda Nazionale Idrogenazione Combustibile, set up in 1936. This concern, half of the capital of which was supplied by the Azienda Generale Italiana Petroli and the Italiana Petroli Albania, is obviously under Government control.

It is said to be processing Albanian crude petroleum at Bari and to have planned or to have under construction plants at Livorno and near Florence for the hydrogenation of crude petroleum, bituminous rock, lignite, and peat. Several other proposals for the employment of hydrogenation and low-temperature carbonization have been announced in the Italian press, none of which are believed to be in production.

Japan reported spending vast sums to manufacture synthetic fuels.—If reports concerning Japanese activities in the field of coal liquefaction are reliable, that country has embarked on a program of synthetic fuel manufacture second only to Germany's. It is said that the Government program calls for the attainment of an annual production of 13,650,000 barrels of synthetic fuels by 1944. Capital investment is placed at around 730,000,000 yen, of which 50,000,000 would be spent on exploitation of oil shale in Manchuria, 325,000,000 for coal hydrogenation, 114,000,000 for gas synthesis, 115,000,000 for low-temperature carbonization, and 127,000,000 for development of coal mines.

Hydrogenation plants now presumably in operation are the Ube Nitrogen, K K using tar, with potential annual output of 850,000 barrels of gasoline, and the Manchurian Chemical Company, having a yearly production of 170,000 barrels of gasoline. A Fischer-Tropsch plant belonging to the Mitsui interests, with an annual output of 190,000 barrels at Miike Kyushu, is scheduled for completion this year, as is the South Manchurian Railway plant of 125,000 barrels annual capacity, using the so-called "Navy" process. Twelve additional projects are planned for the manufacture of synthetic fuels. Some are to employ hydrogenation, others gas synthesis and, still others, low temperature carbonization. Finally, there has been set up the Imperial Fuel Co., with capital reported at 100,000,000 yen, raised partly by public subscription, but under joint Army and Navy administration. This organization is to produce synthetic fuels for the military services.

Cost of synthetic fuels much higher than petroleum fuels.—That the production of synthetic petroleum products from coal is becoming increasingly important in several foreign countries is obvious; it is, or will be, equally apparent that the manufacture of synthetic fuels calls for substantial private investment, a high order of engineering ability, and the assumption of a heavy State burden in the form of subsidies. This is the case even in Germany where conditions have been most propitious.

It is doubtful if any concern, whatever its capital resources and research facilities, could successfully develop a completely new method of liquefying coal. Basic patents are controlled by powerful financial interests. Substantial licensing fees must be paid to Ruhrchemie A. G. for use of the Fischer-Tropsch process, and to International Hydrogenation Patents, Ltd., since 1931, for rights to hydrogenation developed and owned jointly by I. G. Farbenindustrie, the Royal Dutch Shell Combine, the Standard Oil Co. of New Jersey, and Imperial Chemical Industries, Ltd.

It is less expensive to produce synthetic gasoline from a combination of coal, tar, and creosote than from coal because part of the work of liquefaction has already been accomplished. In 1936 Imperial Chemical Industries, Ltd., estimated that it would require about 2 years to erect in England the minimum-sized economic Bergius I. G. unit having a potential annual output of 1,300,000 barrels of gasoline and that its over-all cost would range from $25,000,000 to $40,000,000 depending on whether the combination of coal, tar, and creosote, or only coal, was treated as the raw material. A Fischer-Tropsch plant of minimum economic capacity, say 170,000 barrels of gasoline per year, could be built at a cost of $5,000,000 to $7,500,000. More recent information would indicate that both Bergius-I. G. and Fischer-Tropsch plants of the capacities noted could now be erected substantially under the original estimates.

The cost of producing synthetic gasoline is dependent upon the interrelation of so many factors—cost of lignite, coal, coke, tar, and creosote used as raw materials, charges for power, price of skilled labor, cost of hydrogen (a key consideration), obsolescence allowances for plant, etc.—that it is not possible to state the comparable cost of manufacturing a gallon of synthetic gasoline from country to country. Gasoline obtained from the liquefaction of coal is now produced for 17 to 25 cents per gallon f. o. b. plants in Europe.

Oil From Shale

Extensive deposits of shale, torbanite, and several types of bituminous rock, having a sufficient content of organic matter to warrant their processing for oil, exist in many parts of the world. These are mined much the same as coal is mined. Upon being brought to the surface, the raw material is crushed to a convenient size and then fed into a retort where subjected to destructive distillation, it yields crude oil, gas, ammonia water, and a residue of spent shale. From the crude oil is derived the usual range of liquid fuels obtained from the refining of crude petroleum. Spent shale is now used in some countries for making brick.

Technique of oil-shale exploitation developed largely in Scotland.—At present, the largest shale-oil industry is that located in Mid Lothian County in Scotland. Here, since 1850, have been developed most of the technique and equipment now utilized in producing oil from shale. The Scottish industry achieved its maximum output in 1913 when 3½ million tons of shale were retorted. Since then the mining of shale has fluctuated, mostly downward, being around 1,407,000 tons in 1936. In that year, a ton of shale on the average yielded 26.4 gallons of crude oil. From the crude oil there was refined approximately 30 percent gasoline, 63 percent gas and Diesel oil, with the remaining 7 percent consisting mostly of light shale oil and fuel oil. Reserves of shale in Scotland, though less extensive than in some other countries, are thought to be sufficient for many years.

For about 10 years after the beginning of the exploitation of oil shale in Estonia in 1918, it was utilized almost entirely in place of coal as fuel for the state railroads and for industry. From 1928 through 1937, the mining of shale increased from 446,000 to 1,124,000 metric tons and the recovery of crude oil from 77,700 to 784,000 barrels, and in 1938 is expected to reach 1,300,000 barrels. Production of gasoline in 1937 at 62,000 barrels enabled an export of 45,000 barrels, and, in addition, there was shipped, mostly to nearby countries, 378,000 barrels of crude oil. Estonian shale reserves are said to underlie about 3,000 square kilometers of land and are estimated at 4½ to 6 billion tons of shale.

Oil shale, or as it is generally termed, bituminous schists, has been mined in France since 1838 principally in the region of Autun and Buxieres. By 1864 the industry had attained a state of considerable importance, but after that time imports of low-priced kerosene forced it to sharply curtail operations. In recent years, the Societe-Lyonnaise des Chistes Bitumineaux has operated retorts at Autun, obtaining from 12 to 24 gallons of crude oil per ton of shale. Current output of cracked gasoline ranges from 32,000 to 38,000 barrels from 63,000 barrels of crude oil.

Deposits of oil-bearing earths are said to be located in Spain, Yugoslavia, Italy, Bulgaria, Germany, Czechoslovakia, Switzerland, the Union of Soviet Socialist Republics, Sweden, Finland, and Latvia, but only in the two latter countries are there recent statistics showing the refinery output of gasoline from oil distilled from shale. Finland is recorded as having produced 23,000 barrels of shale gasoline in 1937, while Latvia is credited with about half as much for the same year.

In Africa, oil-bearing shales have been reported found in Morocco, Portuguese West Africa, Belgian Congo, Southern Rhodesia, and in the Union of South Africa. Only torbanite in Natal and Transvaal has been subjected to exploitation, and thus far operations could scarcely be considered successful. The South African Torbanite Mining & Refining Co., Ltd., has found it necessary to import considerable quantities of crude petroleum to be refined in conjunction with the processing of torbanite; only in this manner is the company, at present, able to produce gasoline cheap enough to permit its being sold in competition with imported motor fuel.

Extensive deposits of shale, rich in organic content, are reported to exist throughout South America, particularly in Argentina, Brazil, Chile, and Uruguay, but until shale oil can be produced more economically and/or crude petroleum costs more, it is doubtful if the exploitation of these shales will be attempted on any considerable scale.

Australia to retort Newnes shales.—It is estimated that some $10,000,000 has been lost during the last 30 years in trying to extract, commercially, oil from the Newnes shales, New South Wales, Australia. Sizable deposits exist, and the shale is rich in oil, yielding up to 120 gallons per ton of shale. After several investigations by experts, it was concluded in 1937 that sufficient progress had been achieved in the technique of processing oil shale to warrant further efforts to work the deposits at Newnes. Accordingly, the Commonwealth and New South Wales Government announced that they would contribute $2,500,000, secured by 4½ percent debentures to a venture in which private interests in Sidney would put up $830,000 to develop a shale-oil industry. With adequate preferences it is thought 286,000 barrels of gasoline, about 4 percent of Australia's total annual consumption, could be obtained from the Newnes project. Oil-bearing earths have been found in Tasmania and New Zealand, but there are no recent reports indicating exploitation.

Shale-oil production at Fushan important to Japan.—Serious development of the Manchurian oil shales did not begin until about 1929, when a plant was erected at Fushan with a reported annual throughput of 1,400,000 metric tons of shale. The building of additional retorts and the installation of a cracking unit in recent years have made possible the processing of more shale and the production of higher octane gasoline. Output of crude oil is reported to have increased from 203,000 to nearly 1,000,000 barrels between 1930 and 1937; and, in the latter year the production of gasoline and fuel oil was estimated at 60,000 and 490,000 barrels, respectively. It is said that much of the fuel oil produced at Fushan is reserved for the use of the Japanese Navy.

Occurrences of oil shale have been reported else where in Asia, notably in Mongolia, Arabia, and Syria, but knowledge is incomplete regarding their exact location, extent, and possibilities for the production of oil.

Crude shale oils, if subjected to straight refining, do not yield high octane motor fuel, but if suitably cracked, these oils can be converted into the equivalent of regular grade gasoline. The exploitation of oil shale is initially handicapped by the fact that Scottish practice and equipment is frequently not adaptable to the oil-bearing earths and rocks of other countries, necessitating expensive pioneering work. In most countries at this time, the cost of producing shale gasoline is too high to permit economical operation of a shale-oil industry unless it is protected against imported gasoline. Current cost of shale gasoline is reported to be from 15 to 17 cents per gallon at European plants.

Substitute Motor Fuels

Motor Fuel Blends

Occasionally ethyl alcohol is used alone as motor fuel, but generally it, benzol and methanol (methyl alcohol), are mixed with gasoline. Ethyl alcohol is often referred to as a motor fuel produced from "renewable sources." Although produced synthetically, as well as from waste sulphite liquor at wood-pulp mills, ethyl alcohol is obtained mostly from the fermentation of vegetable matter—cane molasses, sugar beets, potatoes, grape juice, cereal grains, etc. Its manufacture is possible almost anywhere in the world. To blend satisfactorily with gasoline, alcohol should be almost entirely free of water, hence the dilute solution resulting from fermentation is dehydrated to form an alcohol of at least 99.5 percent purity. Methanol is obtained from the distillation of wood, synthetically from natural gas, and by processing gases resulting from the liquefaction of coal. Having less energy content than either benzol or ethyl alcohol, it is not extensively utilized as motor fuel. Benzol is a product of the high-temperature carbonization of coal. Being a byproduct of gas and coke manufacture, the quantity of it available is obviously dependent upon the output of gas and coke, a fact tending to prevent any very large increase in the production of benzol.

AUTHOR'S NOTE.—There is considerable difference of opinion as to whether equally good results can be obtained if use is made of blends of gasoline with alcohol, benzol, or methanol in place of straight gasoline. With the technical merits of motor fuel blends this study is not directly concerned, although it does attempt to summarize the principal economic issues involved. As a means of estimating the relative importance of substitute and synthetic liquid fuels, there is shown in the accompanying table the approximate consumption of internal combustion engine fuels, excluding diesel oil, for various countries converted on the basis of heat energy to the equivalent of gasoline.

TABLE 1.—*Approximate demand for motor fuels in foreign countries making use of nonpetroleum motor fuels in 1937*

(Based on Heat of Combustion)

Countries	Total consumption of motor fuel in terms of gasoline (in 1,000 barrels)	Gasoline from petroleum	Gasoline from coal	Gasoline from shale	Benzol	Alcohol (95 percent or higher, pure)	Compressed petroleum gases	Other gases (estimated)
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
United Kingdom	41,853	93.1	2.7	0.5	3.5	(1)	(1)	(1)
France	23,909	93.4	0.5	(1)	2.0	3.2	(1)	0.8
Germany	22,600	52.2	30.0	(1)	12.2	3.5	2.0	(1)
Japan	[3] 8,160	[2] 99.3	(1)	[2] .7	[2] .5	(1)	(1)	(1)
Sweden	4,366	98.3	(1)	(1)	(1)	1.7	(1)	(1)
Italy	4,338	93.6	(1)	(1)	(1)	4.2	1.2	1.0
Netherlands	3,962	[2] 95.9	(1)	(1)	4.1	(1)	(1)	(1)
Belgium	3,646	[2] 93.4	(1)	(1)	6.6	(1)	(1)	(1)
Brazil	2,959	93.2	(1)	(1)	(1)	6.8	(1)	(1)
Czechoslovakia	2,013	[2] 84.0	(1)	(1)	4.1	11.9	(1)	(1)
Cuba	1,261	97.5	(1)	(1)	(1)	2.3	(1)	(1)
Philippine Islands	1,129	93.3	(1)	(1)	(1)	[4] 6.7	(1)	(1)
Poland	855	88.0	(1)	(1)	7.5	4.6	(1)	(1)
Hungary	368	88.9	(1)	(1)	(1)	11.1	(1)	(1)
Estonia	138	43.5	(1)	56.5	(1)	(1)	(1)	(1)

[1] Under ½ of 1 percent.

[2] Estimated.

[3] Figures for 1936.

[4] Percentage based on figure obtained by dividing by 2 the quantity in "proof" gallons.

Based on U. S. data, probably high for some foreign countries, synthetic and substitute motor fuels converted to equivalent of gasoline as follows:

Motor fuel:	*Calories per gram*
Gasoline	11,250
Benzol	10,100
Alcohol	7,200
Methanol	5,300
Butane—propane	11,900
Methane	13,300
Producer gas	5,000

Benzol and alcohol account for approximately one-seventh of Germany's consumption of motor fuels.—Not only is Germany first in the production and use of synthetic gasoline obtained from the liquefaction of coal; that country is also the heaviest consumer of substitute motor fuels. In 1937, of the total German demand for internal-combustion engine fuel, approximately 12.2 percent was met by benzol and 3.5 percent by alcohol. Government spokesmen say, however, that with the expansion of the manufacture of synthetic fuels, less ethyl and methyl alcohol will be utilized as motor fuel and that eventually their use for that purpose will be discontinued altogether in Germany.

Finding the Reich Alcohol Monopoly possessed of excessive stocks in 1930, the German Government enacted a law requiring light fuel importers and producers to purchase from the Monopoly, ethyl alcohol equal to 2½ percent of the gasoline, kerosene, and benzol handled by them. Within less than 2 years, the proportion of alcohol to be purchased was raised to 3½, 6, and then 10 percent. From 1932 when the 10 percent admixture of ethyl alcohol with gasoline became compulsory (during the 2 preceding years distributors of gasoline were obligated to buy a specified quantity of alcohol, but were not compelled to blend any arbitrary percentage of it with gasoline) through 1935, the annual consumption of motor alcohol in Germany increased from 278,000 to 1,423,000 barrels.

Smaller crops, coupled with an increasing demand for food and feed supplies, acted to curtail considerably the output of ethyl alcohol in 1936 and 1937. At the same time, the mounting production of methanol was seeking new outlets. Accordingly, early in 1936 a regulation became effective which retained the 10 percent blend of alcohol with gasoline but provided that the composition of admixture should be 9 parts of ethyl alcohol to 1 part of methanol. Shortly after, the ratio became 4 to 1, and at present it stands at 2 parts of ethyl alcohol to 1 part of methanol. During the intervening period to date, the percentage of ethyl-alcohol to methanol in the admixture, "Krafspirit" required to be blended with gasoline has remained 2 parts to 1, but the quantity of "Krafspirit" mixed with gasoline increased from 10 to 13 percent October 1, 1937; declined to 10 percent April 1, 1938; and as of September 1938 reverted to 13 percent. The net effect of the measures taken during 1936 and 1937 was to reduce the amount of ethyl alcohol used as motor fuel from 1,270,000 to 1,115,000 barrels and, during the same period, to increase the use of methanol from 244,000 to 555,000 barrels. Larger production of ethyl alcohol in 1938 will enable more "Krafspirit" to be used in motor fuel.

Benzol is now mixed with approximately 40 percent of Germany's motor fuels. Current production ranges from 3,000,000 to 4,000,000 barrels annually and should climb higher as output of coke is expanded and more efficient recovery equipment is installed at both gas and coke plants. Consumption of benzol as motor fuel in Germany was reported at 3,100,000 barrels in 1937, just over twice the figure for ethyl alcohol and methanol.

By a law enacted in 1931, the Finance Minister of Austria was authorized to compel the admixture of 25 percent of alcohol with gasoline as long as the price of alcohol did not exceed the wholesale price of gasoline. The small quantity of alcohol offered for sale resulted in the decree becoming inoperative and, on July 7, 1934, a law was passed requiring importers of gasoline to purchase an amount of alcohol equal to 2 percent by weight of their motor fuel sales; domestic producers of gasoline were obligated to take up alcohol equal to 3.75 percent of their sales. Although required to purchase specified quantities of motor alcohol, the distributors may not blend less than 20 nor more than 40 percent alcohol of 99.5 percent purity with gasoline. From which fact it would seem that the 35,000 barrels of motor alcohol utilized in Austria in 1936 was mixed with only a small proportion of the total gasoline consumed. Since its incorporation with the German Reich, Austria's laws pertaining to motor fuels have probably been made to conform with those of the latter country.

Small quantities of gasoline handled by independent distributors in Belgium contain alcohol, but the amount so utilized is unimportant. Regular grade gasoline is blended with 3 to 8 percent benzol, and premium grades may contain as much as 30 percent. Consumption of motor benzol amounted to 271,000 barrels in 1937, nearly 6.6 percent of the total demand for motor fuel in Belgium.

Benzol to the extent of 182,000 barrels, obtained from the State Mines at Limburg, coke plants and municipal gas works, was utilized as motor fuel during 1936 in the Netherlands. Motor fuel, on the average, contains 5 percent benzol. Commissions set up to inquire into the use of alcohol as motor fuel in the Netherlands thus far have either advised against it or failed to make public their recommendations.

Use of alcohol as motor fuel declining in France.—After the World War, the French Government set up a bureau to encourage agricultural reconstruction and included among its functions that of coordinating the production and sale of alcohol. By 1923 the output of alcohol had grown to exceed ordinary requirements so a law was passed requiring importers of gasoline to purchase 25 to 35 liters of alcohol for each 100 liters of gasoline sold. Abandoning as unsatisfactory the obligatory purchase of alcohol without requiring a specified percentage of admixture with gasoline. in 1928 France enacted a law calling for the compulsory blending of 25-35 percent of alcohol with second-grade gasoline, "Carburant Poids Lourds."

Five years later it was found that output of alcohol was considerably in excess of what was needed for non-motor-fuel uses and for blending with "Carburant Poids Lourds"; in consequence, the French Government authorized the admixture of 10 to 16 percent of alcohol with "Tourisme" or regular grade gasoline. Consumption of motor alcohol increased from 549,000 to 1,430,000 barrels between 1933 and 1934; reached a peak of 2,555,000 barrels in 1935 and by 1937 had declined to 1,220,000 barrels. In the latter year, alcohol accounted for around 3.2 percent of the total French motor fuel demand. Poor crops and diversion to non-motor fuel uses greatly curtailed the availability of motor alcohol after 1935. In line with reduced output, "Tourisme" gasoline since May 1, 1937 has been exempt from admixture with alcohol, although "Carburant Poids Lourds" is still required to contain 25 parts by volume of alcohol.

About 80 percent of the total French consumption of benzol is utilized as motor fuel. Use of it for all purposes increased from around 630,000 to 761,000 barrels between 1932 and 1934. Curtailed imports and lower recovery at gas plants reduced consumption to approximately 715,000 barrels in 1935, but in 1936 it had recovered to about 752,000 barrels. Just under 2 percent of France's total motor fuel consumption is supplied by benzol.

"Dynalkol," a mixture of varying proportions of gasoline, alcohol, and benzol, has been used as motor fuel by several Czechoslovak Government agencies since 1923. Its exact formula is supposed to be kept secret, but according to reliable reports, throughout the alcohol production year of 1936-37, it consisted of 70 percent gasoline, 26 percent ethyl alcohol, and 4 percent benzol. Backed by 9 years of experience with "Dynalkol" which, incidentally, is not sold to private consumers, the Government decreed compulsory admixture of alcohol with gasoline in 1932.

Czechoslovakia requires 12 percent alcohol with gasoline.—On September 1 of that year a law was passed requiring that gasoline not exceeding 0.79 specific gravity be blended with alcohol, and subsequently in 1935, gasoline up to 0.81 specific gravity. "Motor alcohol," supplied at licensed mixing stations by the alcohol cartel, is now composed of 94.5 parts of ethyl alcohol, 2.5 parts of methanol, and 3 parts of gasoline of 0.73 to 0.74 specific gravity. Present mixing regulations require that 20 percent of "motor alcohol" be blended with 80 percent of gasoline. Other special mixtures, mostly "motor alcohol" blended with 20 to 25 parts of benzol, are likewise marketed in Czechoslovakia. The ratio of motor alcohol used to total motor fuel demand in Czechoslovakia is just under 12 percent, while the comparable ratio for benzol is about 4 percent. Consumption of motor fuel, including some 420,000 barrels of alcohol and 93,000 barrels of benzol, amounted to 1,980,000 barrels in 1936.

Italy issued a decree in 1926 obligating importers of gasoline to purchase alcohol. Four years later, admixture of alcohol with gasoline became compulsory and 25 percent of the domestic output was to be set aside for use as motor fuel. Little effort was made to enforce the law, however, and annual consumption scarcely exceeded 13,000 to 60,000 barrels until the rationing of fuel was resorted to during the Ethiopian crisis. Various motor fuel blends have been offered for sale in Italy; during the difficulties with Ethiopia the A. G. I. P. placed "Robur," a mixture of 40 percent gasoline, 30 percent ethyl alcohol, and 22 percent methanol on the market, and more recently, a blend of 70 percent gasoline, 20 percent alcohol, and 10 percent benzol was made available to motorists.

Insufficient alcohol to blend with gasoline in Italy.—The Government has tried through several measures to increase the output of alcohol, and since 1936 the law has called for the blending of 20 percent alcohol with gasoline. The insufficiency of production, however, did not permit more than an average of 4 percent admixture during 1937 and, effective January 1, 1938, the law became inoperative if an amount of money is paid equivalent to the sales tax on the alcohol formerly required to be blended with gasoline. Italian production of benzol and methanol is small, and neither may be utilized as motor fuel without permission of the Government.

The Yugoslav Government decree of 1933 requiring the admixture of 20 parts of alcohol with 80 parts of gasoline was rescinded in November 1934. Since that time there has been some optional buying of blended motor fuel due to its price being lower than that of imported gasoline, on which there is imposed a high rate of duty. Some 18,000 barrels of alcohol were reported to have been mixed with gasoline sold in Yugoslavia in 1936.

Compulsory blending of alcohol with gasoline exceeding 0.735 specific gravity has been effective in Hungary since 1929. Straight gasoline under 0.735 specific gravity is subject to very high sales taxes unless purchased for agricultural use. Approximately 74,000 barrels of alcohol were mixed with gasoline to form "Motalko," a blend of 80 percent gasoline with 20 percent ethyl alcohol in 1936; in terms of total annual consumption motor-fuel alcohol accounted for over 11 percent, the second highest of any country covered in this survey.

Nearly one-eighth of Poland's motor-fuel consumption consists of benzol and alcohol.—Poland decreed compulsory admixture of alcohol with gasoline in 1932 and early in 1933 the petroleum producers agreed to purchase from the alcohol monopoly a quantity of alcohol equivalent to 9 percent of the consumption of motor fuel during the preceding year. It was further agreed that for each 10 percent increase in motor-fuel sales during subsequent years, the petroleum producers would purchase an additional 2 percent of alcohol, but that the maximum percentage of alcohol taken by them should never exceed 30 percent of the preceding year's consumption of motor fuel. This alcohol, forming blends of 22–25 percent alcohol, 5–10 percent benzol, and 65–73 percent gasoline, is contained in about 50 percent of the motor fuel marketed in Poland. In 1937 benzol and alcohol accounted for, respectively, 7.5 and 4.6 percent of the total Polish consumption of motor fuel.

After Germany, Great Britain is the largest consumer of motor benzol in Europe. Production, divided between coke ovens, tar distilling works and gas plants, in the proportion respectively of 58, 23, and 19 percent, amounted to 1,463,000 barrels in 1936. This figure is equivalent to 3.5 percent of the total British consumption of motor fuel in that year. Output has increased steadily since 1932 and is expected to grow larger with the expansion of coke-producing facilities and the installation of improved recovery apparatus. Typical of the benzol-gasoline blends is the mixture of 30 percent benzol and 70 percent gasoline marketed by the National Benzol Association.

As around 90 percent of the ethyl alcohol produced in Great Britain is obtained from imported molasses, and current opinion in that country does not favor the building up of any considerable degree of reliance on home-produced substitute motor fuels, there has been no governmental effort to sponsor the use of alcohol as internal-combustion engine fuel. Nevertheless, various acts of Parliament have tended to encourage the use of ethyl alcohol as motor fuel.

Some demand for alcohol blends in England but sales likely to decline on removal of alcohol preference.—The finance act of 1921 retained the principle of earlier laws in favoring domestically manufactured ethyl alcohol used for power over that intended for human consumption, setting the preference at 15.3 cents per gallon. Under a law passed in 1930, imported alcohol, if mixed with a minimum of 25 percent benzol or gasoline, is free of duty. These exemptions have enabled distributors to place on the British market in recent years motor-fuel blends composed of gasoline, ethyl alcohol, and benzol having a higher-than-average octane rating at prices equal to, or only slightly higher than, regular-grade gasoline. In consequence, consumption of motor alcohol increased from 500 barrels in 1931 to 128,000 barrels in 1937. Since May 2, 1938, alcohol intended for blending with motor gasoline has been subject to the same import duty and excise tax as gasoline, a factor likely to reduce the use of alcohol as a constituent of motor fuel.

Compulsory admixture of 25 percent alcohol with 75 percent gasoline has been effective in Lithuania since April 1, 1936. For the whole of that year approximately 10,000 barrels of potato alcohol were mixed with gasoline to form a blend marketed as "Motorin." As imports of gasoline declined from 42,000 to 37,000 barrels between 1936 and 1937, some replacement of gasoline by alcohol appears in prospect for Lithuania.

Latvia provided for compulsory admixture of alcohol with gasoline in 1931, setting the proportion at 1 part of alcohol to 3 parts of gasoline. Subsequent action changed the ratio to 1 to 1, then 1 to 2, and finally in 1936, gasoline was no longer required to be blended with alcohol. Production of alcohol by Latvia's 50-odd distilleries amounted to 62,000, 85,000, and 55,000 barrels, respectively, in 1934, 1935, and 1936.

Of the Scandinavian countries, only Sweden uses any considerable amount of alcohol in motor fuel. For several years, mixtures such as "Lattbentyl," composed of approximately 75 percent gasoline and 25 percent ethyl alcohol, were sold freely in competition with straight gasoline. Later, the cost of alcohol, obtained from the wood pulp mills, was increased and the sale of "Lattbentyl" and similar blends declined. As a result, in 1934 there was enacted a law requiring importers and producers of motor fuel to purchase a prescribed amount of alcohol to be fixed quarterly by the Government. The quantity set has been dependent upon the extent of the surplus of alcohol; for July-September 1938, distributors were obligated to take alcohol equivalent in volume to 2.5 percent of the total Swedish demand for motor fuel during that quarter. Required purchases of alcohol amounted to 121,000 barrels in 1937, an increase of nearly 20,000 barrels over the preceding year.

"New Union Motor Spirit," a mixture of 40 percent alcohol with 60 percent gasoline, is offered for sale in the Union of South Africa. Its distribution is limited principally to Natal Province and the city of Durban, location of the largest alcohol producer, the Natal Cane By-Products Co. Recent alcohol output figures are not available; 4 or 5 years ago they approximated 21,000 barrels annually. Admixture of alcohol with gasoline is not compulsory.

Brazil and Chile only countries in South America requiring the admixture of alcohol with gasoline.—The purchase of alcohol-gasoline blends is optional in Cuba and Panama, and in Argentina, Colombia, and Peru; bills introduced to effect compulsory blending have failed of enactment. No action is known to have been taken with regard to a decree to set up a Government-sponsored alcohol distillery in Guatemala.

The Instituto do Assucar e do Alcool was established in Brazil in 1933 to promote the production of anhydrous alcohol. It extends technical and financial aid to sugar mills desiring to install alcohol distilleries and has authority to fix the proportion of alcohol to be blended with gasoline. Through 1936 it appears that the domestic output of ethyl alcohol was insufficient to permit full enforcement of the regulation obligating importers of gasoline to purchase alcohol equal to 5 percent of the volume of gasoline brought into Brazil. In 1937, however, approximately 324,000 barrels of alcohol were used in blends containing 85 to 90 percent gasoline, indicating that current consumption of motor alcohol is close to 7 percent of the total consumption of motor fuel. Until September 23, of this year, only importers of gasoline were required to purchase motor alcohol; on that date a decree became effective requiring refiners of crude petroleum in Brazil to add alcohol to gasoline in proportion fixed by the National Petroleum Council and the Instituto do Assucar e do Alcool.

When blending of alcohol with gasoline was first considered in Chile an admixture of 25 percent by volume was proposed. As passed, the law specified 9 percent, but when it became effective 6 percent was the proportion required. The ratio of alcohol mixed with gasoline in Chile has varied from year to year; effective June 10, 1938, it became compulsory to blend 3 percent alcohol with the 3 lowest grades of gasoline sold only in the Central Provinces of Santiago, Aconcagua, and Valparaiso. Domestic consumption of motor alcohol manufactured mostly from molasses imported from Peru amounted to approximately 11,000 barrels in 1937.

Small demand for alcohol-gasoline in Panama.—The Government of Panama in 1934 issued a decree dealing broadly with the importation, storage, distribution, and marketing of motor fuel in that country. One provision sought to encourage the use of locally produced ethyl alcohol as motor fuel by exempting from payment of duty gasoline imported for use in blended motor fuels. One of these, "Alcoholina," experienced a considerable volume of sales as long as it undersold gasoline by 5 cents per gallon. Since its price has been equalized with straight gasoline, "Alcoholina" has declined in popularity.

A blend of 80 percent gasoline and 20 percent ethyl alcohol, known as "Espiritu," was offered for sale in Cuba soon after the World War. It experienced few sales. Several bills to provide for the compulsory use of alcohol in motor fuel have been presented to the legislature, but all failed of enactment. However, blended motor fuels have been sold in Cuba since 1931. Nofuco, the most popular, is composed of 64 percent ethyl alcohol, 22 percent gasoline, 8 percent "tractorine," 3 percent gas oil, and 3 percent benzol. Around 76,000 barrels or 2 percent of Cuba's total consumption of motor fuel contained alcohol in 1937.

Alcohol used alone as motor fuel in Philippines.—Being a large producer of cane sugar, the Philippine Islands have a surplus of ethyl alcohol which is utilized as motor fuel. In thousands of proof gallons output amounted to 18,213 in 1936, 22,869 in 1937, and is estimated at around 20,077 for 1938. Of the 1937 production, in thousands of proof gallons, 21,744 were denatured; of this latter amount 20,492 were used for motive power. In the Philippines, alcohol is utilized both in blends and by itself as motor fuel. It is thought to be one of the very few countries in which any considerable quantity of straight ethyl alcohol is used alone as fuel for internal-combustion engines.

"Gasanol," a mixture of 75 percent alcohol, 20 percent gasoline, and 5 percent kerosene, is said to have a fair sale among operators of trucks, buses, and taxis and to be available to the general public at service stations. It undersells regular grade gasoline. According to reports, the Batangas Transportation Co. in Manila is now operating all of its 158 buses and trucks on straight alcohol, and in addition, 2 large bus companies and a mining concern on Luzon Island and the transportation agencies on Negros and Panay use the same fuel. Taking into consideration the cost of converting an engine from gasoline to alcohol, the necessity of more mechanical service and less mileage, alcohol, to be utilized by itself as motor fuel, should sell for approximately 30 percent under imported gasoline in the Philippines. Several bills have been presented to the legislature to effect compulsory blending of alcohol up to 25 percent with gasoline, but the sugar interests have felt reasonably well satisfied with existing outlets for the disposition of alcohol, and the Government has seemed unwilling to forego the revenue resulting from duties imposed on imports of gasoline.

Plan increase of fuel blend consumption in Australia.—Use of alcohol in motor fuel in Australia is confined to Queensland; in that State distributors of gasoline are required to purchase from the Australian National Power Alcohol Distillers dehydrated alcohol equal to 1½ percent of the volume of gasoline handled by them. Production of ethyl alcohol, now averaging

21,000 barrels a year, is expected to double if the new distillery of the Colonial Sugar Refining Co. at Plymouth is operated at full capacity. Considerably more benzol than alcohol is utilized as motor fuel in Australia, and it is expected that benzol will be relied upon as a national motor fuel to an increasing extent in coming years. Annual production for all purposes is currently around 71,000 barrels, mostly from the coke ovens belonging to By-Products Ltd. at Newcastle. It is claimed that this output could be doubled and that, in addition, 100,000 barrels of benzol could be obtained from the coke ovens at Kimbla. Potential recovery would be even larger if the various State governments could be persuaded to authorize a lowering of the heat content of gas intended for domestic consumption.

Although India is a large producer of sugar cane, the Central Government does not favor the use of alcohol as motor fuel. Provincial authorities are divided: a United Provinces committee recently reported that, in its opinion a cheap and regular supply of molasses, adequate labor, and a large market would assure success if the residue could be disposed of as cattle feed, for fertilizer and soil reclamation; a Bombay committee about the same time advised against that Provincial government sponsoring the manufacture of motor alcohol from cane molasses and mohara flowers. However, in Mysore, one of the most progressive of Indian native states, molasses from the State sugar factory is converted into dehydrated alcohol by the Melle process, and is said to be utilized satisfactorily without blending with gasoline in vehicles operated by the State of Mysore.

Japan decrees compulsory admixture of alcohol with gasoline.—Determined not to overlook any means of becoming less dependent upon imports of liquid fuels, Japan enacted a law requiring the blending of alcohol with gasoline, March 31, 1937, and the next day backed it up with the alcohol-monopoly law which authorizes the Government to control output of alcohol, reserve to itself imports and exports, fix prices, and monopolize distribution. The compulsory admixture law, authorizing the blending of alcohol up to 20 percent, was scheduled to become effective October 1, 1937, but did not become operative until July 1, 1938. The proportion was first set at 2½ percent alcohol to 97½ percent gasoline, but shortly was raised to 5 and 95 percent.

Required use of alcohol in motor fuel has not been effective in Japan long enough to ascertain its degree of success. It would seem that if any considerable quantities of alcohol are to be used in motor fuel, production at the 1936 level of 44,000 barrels of ethyl alcohol and 30,000 barrels of methanol would have to be substantially increased. To meet the expected expansion in demand, the Government of Japan proper, as well as those of Taiwan, Chosen, and Manchuria, and the associated regime of North China have announced numerous ambitious projects.

In a majority of the countries not included in the discussion of motor-fuel blends, there has been considerable investigation of the use of alcohol as motor fuel. Benzol is universally esteemed for blending with gasoline to improve anti-knock quality, and it is not generally thought of as a competitor of gasoline. Costs of production of ethyl alcohol, methanol, and benzol vary too widely to permit a generalized statement of their costs in comparison with gasoline.

Substitute Fuels

Gases, Vegetable Oils, Coal Dust, Etc.

The term "miscellaneous substitute fuels" is here considered to include any substance aside from petroleum, oil shale, synthetic fuels derived from coal and the motor-fuel blends, capable of supplying energy utilizable as internal-combustion engine fuel, but this section of the study is primarily concerned with gases and materials for their generation adaptable for use as motor fuel. Few, if any, of the other miscellaneous fuels have achieved the stage of commercial exploitation.

Compressed gas used directly in place of gasoline, but producer gas requires special equipment.—Most important are the gases utilized in the compressed state—coal gas (city gas, mine gas, "Ruhrgas," etc.)—resulting from the carbonization of coal; butane, propane, and pentane obtained principally from the liquefaction of coal and the cracking of petroleum; and natural gas. Usually, the high energy content of these gases enable them to be used satisfactorily in the ordinary automobile engine. They are supplied at service stations, where metal cylinders containing, on the average, propane-butane equivalent to 18 gallons of gasoline, methane equivalent to 4.6 gallons of gasoline, and coal gas equivalent to 1.8 gallons of gasoline are refilled for the motorist. Compressed gases are also used abroad for light and heat, much the same as "bottled" gas in this country.

The utilization of compressed gases as motor fuel is a comparatively recent development, but producer gas generated from wood, charcoal, and coal was used as fuel for stationary engines as early as 1900. Since the World War there has been a steady development of gas generator-power units, or gasogene motors, as they are generally referred to, adaptable for use on automobiles and tractors as well as stationary installations. In these, power is developed by the generation of gas from the retarded combustion of wood, charcoal, peat, anthracite or bituminous coal, coke or briquetts, passed through filters to remove impurities, and then led through a mixing valve from which it emerges mixed with air in the proper proportion for explosion in the combustion chamber of the engine. Being low in energy content, producer gas can only be used satisfactorily in automobile engines of higher than average compression ratio.

Germany largest consumer of compressed gases.—At the end of 1937 there were approximately 12,000 vehicles, mostly trucks of 2 or more tons capacity, operating principally on propane, butane, and "Ruhrgas" in Germany, and during 1938 another 10,000 are expected to be converted to gas. Improved arrangements for carrying the gas cylinders now enable a weight saving of 40 percent over the old-style container. According to a recent report, propane and butane are now being used to drive Zeppelin airships. Consumption of compressed gases as motor fuel probably reached 112,000,000 pounds in 1937, and if plans materialize, nearly double that quantity will be used during 1938. The use of compressed gases of low energy content, such as city gas and clear gas, is likewise gaining as motor fuel in Germany, particularly for municipally owned vehicles. At the end of 1937, 500 such automobiles were in service.

Some 2,000-odd motorcars in Germany are equipped with producer gas or gasogene units. Fuel in convenient form is now available for these vehicles at numerous stations. Gasoline-driven cars are converted to the use of producer gas in Germany at a standard charge of $160 to $170. Coal is not generally used as gasogene fuel in Germany, but hard coal is said to be serving satisfactorily as fuel for several Diesel-type railway engines operating on producer gas.

Public service vehicles to be gasogene operated in France and Italy.—Compressed gases are not yet extensively used in France as motor fuel, but that country has in service probably the largest number of gasogene vehicles. A decree became effective in 1937 which obligates bus and truck fleet operators of 10 or more vehicles to utilize wood, or motor fuel derived from wood, in at least 10 percent of their cars by July 1, 1939. A later decree authorized the Ministry of Public Works to permit national materials other than wood to be utilized for motor fuel. In this connection, considerable interest attaches to the development of "Carbonite," a highly concentrated form of charcoal said to be ideally suited as fuel for producer gas automobiles. An exposition devoted to gasogene cars was held in the spring of this year at Paris. Exhibits included cars and chasses by Berliet, Renault, Latel, Delahaye, Licorne, and Unis as well as accessories, equipment, and special fuels for gasogene engines.

In endeavoring to coordinate the production of fuels from domestic materials, Italy has tested practically all of the better known fuel gases for use as motor fuel. In 1935 a decree was published requiring all automobiles operated for public service to be equipped to utilize nonpetroleum fuels by December 31, 1937, and on January 1, 1938, it was estimated that 7,500 vehicles affected by the law would use fuel as follows: 3,000 national fuels or electricity, 2,000 on naphtha, 2,000 on producer gas, and 500 on compressed gases. Substantial deposits of natural methane, so-called marsh gas, are being developed in Italy, particularly in the Province of Ferrara, and there are now several stations in that region where automobiles operating on compressed gas may obtain fuel. Liquid ammonia is being tried as motor fuel by the S. I. R. I. Company of Terni, but thus far technical difficulties seem to render impractical its extensive use as an internal combustion engine propellant. Acetylene, after several tests, has been prohibited by the Government for use as motor fuel.

Practically all European countries encourage use of "national motor fuels."—Neither compressed gases nor producer gas is much used as a propellant for automobiles in Great Britain. Stationary gas engines, utilizing wood waste, however, power numerous saw mills and wood-working plants; and one such installation of 1,900 brake horsepower is said to be giving highly satisfactory results in Southern Rhodesia.

Several of the remaining European countries have a few gas-driven vehicles in service. The municipal government of Vienna in Austria and the Vitkavice Iron and Steel Works in Czechoslovakia own trucks driven by compressed illuminating gas. Gasogene vehicles are operated by the Swiss Post Office Department and by various Government agencies in Sweden. Buses belonging to the Forestry Ministry in Lithuania were reported recently to have changed from producer gas to gasoline. Automobiles in Belgium now are not required to use producer gas, although the Government offers certain tax exemptions to gasogene vehicles. The official Soviet trade paper, "Industrialization," reports that a wood burning tractor has been tested successfully and that numerous gasogene automobiles are in service in the Union of Soviet Socialist Republics.

The agricultural authorities of the State of Minas Geraes, Brazil, are reported to be much interested in the recent trials of an American truck equipped with a German gasogene unit. In 1936 approximately 1,000 trucks and buses, as well as numerous small stationary installations, in China were reported operating on charcoal gas. Japan is said to have 2,000 trucks and buses equipped with charcoal gas generators. According to the Vancouver branch of the Forest Products Laboratories of Canada, producer gas could be used advantageously as motor fuel in large areas of the interior of that country where gasoline is not easily available.

Propane, butane, and "Ruhrgas" are sold currently in Germany at $18.15 per 220 pounds against $19.20 for the same quantity of gasoline. This saving of 5½ percent plus an average energy content of 11,000 calories for the gases compared to 10,000 calories for gasoline is said to result in a substantial saving in favor of compressed gas.

The cost of converting gasoline-driven vehicles in Europe to producer gas ranges from $150 to $300 and a new gasogene automobile is more expensive than a gasoline car. A producer gas automobile must provide space for the gas generator unit and for the carriage of solid fuel, resulting in additional weight of several hundred pounds, which reduces the car's transport power. Gasogene vehicles are slow starting, usually requiring 5 to 10 minutes to attain smooth running. The cost of operating a producer gas automobile depends upon fuel used. According to recent reports from Germany, 20 to 24 pounds of properly dried wood or 10 to 12½ pounds of charcoal will furnish about the same power as a gallon of gasoline.

Use of miscellaneous motor fuels other than gases still in experimental stage.—Rudolf Pawlikowski, collaborator of Diesel in Germany, has developed an engine which is said to utilize, as fuel, coal dust under heavy pressure. Internal-combustion motors have been operated on creosote oil with some success in both England and Germany. From China comes a report of a Diesel motor bus driven 2,000 miles on vegetable oils, including those extracted from peanuts, tea leaves, tung, poppy seed, cotton seed, and cabbage seed. The trial indicated an average of 7¾ to 8 miles per gallon. Data dealing with coal dust and vegetable oils as motor fuel are too fragmentary for satisfactory comparisons with gasoline.

Conclusion

As liquid fuels, especially motor fuels, are so indispensable to our present state of civilization for national defense, industry and pleasure, it is but natural that nations not possessing adequate supplies of petroleum should seek to obtain ownership of them outside their boundaries, or endeavor to produce synthetic liquid fuels from domestic resources. And certainly commendable progress has been achieved in the latter direction. Thus far, however, taking into consideration the present stage of development of the internal combustion engine, it is only possible for synthetic and substitute motor fuels to compete with petroleum gasoline if the latter is sold to the public at a price 2 times and upward the cost of that gasoline c. i. f. principal European ports.

Synthetic and substitute motor fuels generally unable to compete on price basis with gasoline.—Gasoline obtained from the liquefaction of coal, as pointed out, probably costs from 17 to 25 cents per gallon at plant. Price comparisons of gasoline with motor fuel blends are difficult because mixtures vary, the energy content of the fuels differs, and the cost of producing ethyl alcohol, benzol, and methanol is far from comparable from country to country. Price comparisons of gasoline with gaseous motor fuels are even more awkward. The energy content of certain compressed gases—propane, butane, pentane, and "Ruhrgas" is higher per unit than gasoline, but production costs are not accurately known, and utilization of compressed gas adds weight to the car in the form of containers. Gasogene vehicles appear to operate less expensively than gasoline-driven automobiles. When it is considered, however, that to utilize producer gas the vehicle must be rebuilt or specially designed to house a gas generator and provide space for solid fuel and that its motor must be reconstructed, or built, to run on gas of low energy content, there is some question as to the ability of producer gas to compete with gasoline.

The price advantage of gasoline over synthetic and substitute motor fuels may be equalized in one or more of several ways. Gasoline may be made expensive by the imposition of high import duties, its entry into the country limited because of quotas or exchange restrictions; both domestically produced and imported gasoline are not infrequently subjected to high sales taxes. Assistance to motor fuels competing with gasoline may take any one or a combination of several forms. Synthetic fuels obtained from coal and shale are usually exempted from excise and other taxes, thereby enjoying a preference at least equal to the duty on imported gasoline, and may obtain financial aid from the Government for plant construction either as an outright grant or as a long-term loan at a low rate of interest. Alcohol, benzol, and methanol are nearly always exempted from some or all taxes and, in addition, often receive substantial direct subsidies from the Government through their sale as motor fuel at prices under those paid the domestic producer. The use of gaseous motor fuels is being promoted by State regulation of compressed gas distribution, by standardizing the charges for conversion of gasoline cars to gas, by remission of taxes assessed against the automobile, and by compelling Government-operated and public-service vehicles to utilize "national fuels."

Extensive use of nonpetroleum motor fuels entails forfeiture of large sums in customs revenues and internal taxes.—It is apparent that every gallon of imported gasoline displaced by an equivalent amount of domestically produced synthetic or substitute motor fuel costs the State, if it exempts the home-produced fuels from taxes, an amount of money equal to at least the duty collected on imported gasoline. By this practice alone, foreign governments, particularly Germany, are surrendering many millions of dollars each year in the equivalent of customs revenues. Even an approximate estimate of losses incurred through remission of internal taxes and direct State aid by various countries in promoting the use of substitute fuel is outside the province of this study. The accompanying table shows the high retail prices of motor fuel in several foreign countries.

TABLE 2.—*Retail prices of gasoline in some countries promoting the use of nonpetroleum motor fuels*

[Prices in cents per American gallon as of Oct. 10, 1938]

City and country	Retail price	Import duty and taxes included in retail price
London, England	31.4	14.9
Berlin, Germany	59.6	36.0
Paris, France	27.5-30.5	17.9
Tokyo, Japan	20.0	4.9
Stockholm, Sweden	25.0	11.1
Rome, Italy	81.0	51.0
Rotterdam, Netherlands [1]	30.0	15.0
Antwerp, Belgium	36.0	20.0
Rio de Janeiro, Brazil	24.9	8.8
Prague, Czechoslovakia	41.7	15.8
Habana, Cuba	30.0	16.6
Manila, Philippine Islands	28.4	9.5
Warsaw, Poland	39.0	11.0
Budapest, Hungary	35.0	26.0
Tallin, Estonia	34.0	21.0

[1] Price as of July 10, 1937.

Provision for national defense and other State policies promote use of synthetic and substitute fuels.—But more than economic considerations apply to the utilization of synthetic and substitute fuels abroad; frequently there are involved grave questions of national policy. It is freely admitted that many foreign countries are sponsoring the use of nonpetroleum motor fuels as a means of becoming less dependent upon imports in time of war. This statement is largely true as regards synthetic fuels, but only part of the story concerning substitute fuels. It is reported that little use of alcohol motor fuel blends is contemplated for military vehicles and aircraft; that in several countries the production of alcohol is being built up by requiring its use as motor fuel in order to assure adequate stocks for the manufacture of armament and medical supplies, and that benzol, too, would be largely diverted to the production of munitions for war. Still other reasons may seem to justify, or not to justify, the utilization of substitute fuels. A nation may wish to use motor fuel blends even though gasoline is cheaper on the world market, because of the unavailability of foreign exchange, or frankly to subsidize agriculture, or some branch of industry. On the other hand, the government of a particular country in a position to manufacture alcohol and benzol cheaply may prefer not to encourage their use as motor fuel, appreciating that the displacement of any considerable quantity of imported gasoline would seriously reduce customs revenues. It is not always possible to assay the foregoing considerations in terms of the money value of competing fuels.

United States keeping abreast of developments in nonpetroleum motor fuels.—Although this section of the Energy Resources Survey deals with use abroad of synthetic and substitute motor fuels, it is appropriate to recall that consideration is being given to the feasibility of utilizing such motor fuels in the United States. Experiments in connection with hydrogenation are being conducted in the laboratories of the Bureau of Mines and several of the oil companies, and one of the largest American petroleum companies is a member of the International Hydrogenation Patents, Ltd., which controls the world-wide rights to the Bergius-I. G. process. Moreover, there are at least two commercial hydrogenation plants working on petroleum in the United States. As yet there is little, if any, commercial exploitation of oil shales in this country. In the future, however, the shales of Colorado, Nevada, Utah, and Wyoming particularly, may become a very important source of mineral oil supply. Blended motor fuels, commonly referred to as "alky-gas", are being sold in some of the Central Western States. These are the subject of another section of the Energy Resources Survey, prepared by Mr. P. Burke Jacobs of the Department of Agriculture. Liquid petroleum gases, especially butane and propane, are being utilized to an increasing extent in this country as motor fuel for trucks, buses, tractors, and stationary engines. On the West Coast some trucks used for the transport of fresh food products have been equipped for butane gas, which not only furnishes propulsion but through vaporization produces refrigeration.

For the present, fortunately, the United States has natural petroleum more than ample to meet domestic requirements for motor fuel, heating oils, fuel oils, lubricants, etc. If, in the future, alternative sources of these products need to be found, American ingenuity can be counted on to solve the problem. Foreign experience in the field of substitute and synthetic fuels would be useful as a guide to this country's technicians in their initial efforts to develop a nonpetroleum liquid fuels industry. The vast size and diversified nature of the fuel requirements of the United States, however, would necessitate the development of processes and techniques more economical and efficient and capable of producing a greater range of products than those now employed in Europe.

CHAPTER 3.—MOTOR FUELS FROM AGRICULTURAL PRODUCTS

By P. Burke Jacobs*

The possibility of economic production of alcohol or other suitable compounds from farm products or wood, and the successful use of such derived products as ingredients in a blended motor fuel as a means of aiding agriculture or of conserving petroleum resources, although desirable, involve many technical, legal, and economic problems. Recognition should be given to the fact that irreplaceable national petroleum reserves are being consumed at a rapid rate, with eventual approach of scarcity and higher prices; and sources of replacement fuels should be explored now, to assure continued supply, even though engines of the future may differ in design and in fuel requirements from the present types. Engine design will no doubt be adapted to use the fuels economically available in any period. The problem should be considered in light of both the present and the future situation.

Alcohol blends and similar substitute fuels, as now visualized, have of themselves no intrinsic superiority over gasoline. The present low price of gasoline and of other petroleum fuels, in comparison with the usual production costs of alcohol or of other suitable compounds derived from farm materials, requires that certain fundamental decisions be made before commercial use of such higher price substitute fuels can be effected with prospect of economic success. The determination of whether the use of blended fuels in the immediate future is to be of national or of local scope, and whether such use is to be adopted principally as a national conservation measure or as an agricultural measure, is necessary.

The present annual national consumption of gasoline as a motor fuel is around 22 billion gallons, requiring about a billion barrels (of 42 gallons) of crude petroleum as raw material. A 10-percent alcohol blend would, therefore, require, on a national use basis, approximately 2,200 million gallons of alcohol or equivalent compound. The total present alcohol fermentation and distillation production capacity of the United States is only about 600 million gallons annually, divided rather equally between industrial alcohol plants and beverage spirit (whiskey, gin, rum, etc.) plants. Perhaps half of this total capacity might now be available for motor fuel spirit production, due to limitation of present markets for alcohol and spirits. In case of war or of similar exceptional conditions, this excess capacity would probably not be available. Around 300 alcohol plants of 20,000 gallons daily production capacity each would, therefore, be required to produce the necessary alcohol, at a required capital investment of approximately 250 million dollars. This expenditure would, however, tend to offset future national expenses likely to be incurred through shifting of acreages to new crops, increased investments required to maintain petroleum production, employment of labor, and similar items.

Commercial employment of alcohol blends or other substitute fuels may involve higher fuel costs which would have to be met in some manner. A considerable percentage of the motoring public will doubtless prefer to continue to use unblended gasoline because of the probable lower cost and the past satisfactory performance of gasoline fuels in motor cars of present design. Since competition between straight gasoline and replacement fuels or blends is hardly possible on an equal cost basis at present, and since substitution of other fuels would have certain economic effects on the existing petroleum industry, particularly on the present distribution system, while use of fuels of irregular and varying compositions may cause dissatisfaction to the motoring public, marketing of new fuel products must be effected in such a manner as to avoid creating conditions adverse to the best interests of motorists and of the petroleum and associated industries. Suitable means would have to be evolved to bring the new products into commercial use without adverse effect on the existing fuel situation, without undue increase in cost to the public, and without the introduction of motoring difficulties.

From the agricultural standpoint, a replacement fuel program might visualize merely the advantageous utilization of present unsalable crop surpluses, culls, byproducts and wastes to eke out farm income, or it might be based on a concept of crop-price stabilization through removal of considerable quantities of crops from food or feed markets by increased industrial use of farm products. An agricultural fuel program might also be conceived on the basis of an enlarged agricultural production of crops intended specifically for industrial use. These latter concepts would predicate the existence of large industrial outlets. At present, motor fuel is the only likely market where the great quantities involved could be absorbed without undue readjustment.

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Present low sale prices due to low-cost competitive gasoline and relatively high replacement fuel-production costs bring about a condition under which farm products, used for fuel production, can yield only low returns to the farmer under present crop-raising systems. Furthermore, despite occasional surpluses of the various crops, the year-to-year amounts of surplus and culls or wastes which might be available as motor fuel raw materials, under present crop-raising limitations, would be inadequate to provide sufficient alcohol for a national use of a blended fuel of a definite composition involving 10 percent of alcohol or an equivalent material. At present, also, the manufacturing plant capacity for producing the required alcohol does not exist, and the mechanism of Government control, as now constituted, to avoid illegal diversion or use of tax-free alcohol would be inadequate; and effective denaturants for such alcohol are lacking. A period of at least five years might be necessary to change sufficiently the existing situation in all these respects.

A certain amount of alcohol could be produced immediately, and a gradual but definitely limited expansion of available materials and processing facilities would be possible within the limits set by the prices which might be paid for raw materials, or the returns which might be secured from the sale of by-products of the process. With present crop production, the removal for industrial purposes of any significant amounts of farm products from the food and feed market would immediately result in price increases. Prices of crops for industrial use on any large scale would soon rise to impractical levels and limit such consumption. While, therefore, the industrial utilization of crops might be employed as a definite crop price-raising expedient, the farmer may not actually be benefited, as gains in cash income might be considerably offset by higher food and feed costs, and, in the case of motor fuels, by the fact that the farm population annually consumes perhaps 25 percent of the national motor fuel used, and, therefore, would bear a proportionate share of any increased fuel costs.

Present crops might yield the amounts of alcohol shown in table 3.

TABLE 3.—*Quantities of alcohol obtainable from various crops as now produced in the United States*

Material	Average production, 1928–32	Unit	Average acreage, 1928–32	Alcohol producible per unit, wine gallons [1]	Alcohol producible from total crop, wine gallons [1]	Alcohol producible from 15 percent of crop, wine gallons [1]
Apples	161,333,000	Bushel		0.35	56,466,550	8,469,982
Barley	281,237,000	do	12,645,000	1.90	534,350,300	80,152,545
Buckwheat	8,277,000	do	568,000	2.00	16,554,000	2,483,100
Corn	2,554,772,000	do	103,419,000	2.35	6,003,711,200	900,557,130
Grain sorghum	97,760,000	do	7,016,000	2.22	217,027,200	32,554,080
Grapes	2,199,679	Ton		15.1	33,215,150	4,982,273
Jerusalem artichokes [2]				20.0		
Oats	1,215,102,000	Bushel	40,015,000	1.02	1,239,404,040	185,910,606
Peaches	56,451,000	do		.28	15,806,280	2,370,942
Pears	23,146,000	do		.29	6,712,340	1,006,851
Plums and prunes	365,831	Ton		10.9	3,987,590	598,138
Potatoes (white)	372,115,000	Bushel	3,327,300	.69	256,759,350	38,513,903
Rice (rough)	42,826,000	do	925,000	1.79	76,658,540	11,498,782
Rye	38,212,000	do	3,315,000	2.2	84,066,400	12,609,960
Sweetpotatoes	66,368,000	do	771,000	.94	62,385,920	9,357,888
Sugar beets	8,118,000	Ton	717,000	22.1	194,877,800	29,231,670
Sugarcane	4,994,000	do	266,000	15.2	75,908,800	11,386,320
Wheat	864,532,000	Bushel	60,138,000	2.57	2,221,847,240	333,277,085
Total					11,099,741,700	1,664,961,255

[1] United States wine gallons of alcohol at 99.6 percent by volume, estimated on average analysis of the several raw materials.
[2] No present commercial production.

Since it is probable that, as a general year-to-year average, only 15 percent of any crop could be diverted to industrial use under existing conditions without appreciable effect on the price structure (this percentage including present surpluses, culls, and wastes), the total alcohol shown as producible from the 18 crops listed would represent only about a 7.5-percent blend of the present amount of gasoline annually used in the United States. Few alcohol processing plants are now situated in areas sufficiently close to crop production to make effective use of this material. Haulage of crop materials over any great distances would involve prohibitive costs. The low prices which could be paid for materials at alcohol plants would not tend to stimulate collection and haulage, except of nearby material. Any program limited to the use of such excess materials at present will involve the production of restricted and variable amounts of alcohol, at a great range of production costs.

Alcohol plants forced to operate on the poorer types of raw materials by reason of geographical location would have to market relatively high-priced alcohol in competition with plants situated near better raw materials. Also, since perishable materials cannot be stored and would have to be processed immediately, plants could not operate through the year on such materials and would have to base winter operations on supplementary materials, such as grain or molasses. Alcohol plants require trained personnel, and such staffs would necessarily have to be carried over inactive periods. From an economy standpoint, alcohol production should be carried out on the largest possible scale without shut-downs. A national industry utilizing only culls or excess crops would fail through enforced periods of inactivity as well as from internal competition, unless such industry were organized on a basis whereby these problems could be equitably adjusted, with a sufficient raw-material supply for year-round operation assured. Alcohol produced from farm crops may have to compete with cheaper alcohol produced from molasses or synthetically from ethylene gas. Furthermore, the blended fuel made from such alcohol would have to compete directly with lower cost gasoline, unless some definite marketing arrangement be formulated in advance.

The only materials now used in alcohol-distillation plants are waste cane molasses (the principal source of industrial alcohol), corn, barley, rye, rice, grapes, and apples. The cereal grains are used mainly for whiskey production, corn being used in small amounts as a source of industrial alcohol. Grapes are used only for brandy and wine, and apples for apple brandy. The consumption of the several agricultural raw materials in producing industrial or beverage alcohol is shown in table 4.

TABLE 4.—*Farm materials used by the distilling industry*[1]

Material[2]	For industrial alcohol	For distilled spirits	Total
Molasses (principally cane black strap) gallons	202,631,056	5,349,660	208,070,716
Corn bushels	3,544,066	32,698,074	36,242,140
Barley (as malt,[3] calculated to original barley) bushels	782,012	5,812,740	
Barley (as grain) do	5,343	5,126	6,605,221
Rye do	518	11,551,306	11,633,158
Wheat do		54,311	
Grapes (including raisins)[4] tons		[5] 390,000	
Apples[4] bushels		[5] 131,024	

[1] Fiscal year 1937. Fermentation processes not employing distillation are not included.

[2] Brewing, cereal beverage, and wine industries not included.

[3] Barley malt produced for other than spirit purposes is not included.

[4] Includes brandy produced for wine-fortification purposes, but excludes pomace, wash, etc.

[5] Estimated.

NOTE.—Small amounts of oats, rice, sweetpotatoes, sorgo, pineapple juice, corn sirup, cider, wine, apricots, prunes, peaches, etc.

The producer of agricultural raw material is particularly interested in the acre income return securable from the material, while the industrialist is more concerned with tonnage yields and costs. The ton and acre returns for certain materials are approximately as follows, based on present varieties and yields:

	Gallons of alcohol per ton	Gallons of alcohol per acre
Wheat	85.0	33.0
Wood	70.0	[1] 70.0
Corn	84.0	88.8
Raisins	81.4	102.0
Sweetpotatoes	34.2	141.0
Potatoes, white	22.9	178.0
Sugarcane	15.2	268.0
Sugar beet	22.1	287.0

[1] Estimated.

It is apparent that corn and wheat, most interesting to the industrialist, yield lower returns per acre. At the same time, alcohol production costs for the materials of greater interest to the farmer are too high.

Present alcohol plant and processing costs are such that only the more concentrated materials, such as corn, can be employed competitively against blackstrap molasses as a source of alcohol. The processes of making alcohol or alcoholic beverages are largely conventionalized, and many possible raw materials have not been employed because of higher material or operating costs, effect on odor or flavor, etc. Future research will be necessary to establish the relative value of these other materials as alcohol sources. Since motor fuel alcohol need not be bound by purity limitations, great latitude is possible in the type of process, equipment, and raw material employed. It may be possible to reduce alcohol production costs through new discoveries in this field. Large-scale motor fuel alcohol production need not be concerned with present molasses alcohol cost criteria, since the small excess of molasses would quickly be absorbed in such an extended program.

Recent experiments on the manufacture and sale of power alcohol in the Mississippi Valley, while demonstrating the usability of blended fuels, have not yet convincingly demonstrated that present economic difficulties can be adequately overcome.

Alcohol price depends largely on raw material and conversion costs and byproduct credits. The conversion cost remains more or less constant for a given material, but the price of the material may fluctuate widely. Returns from stock feed, fusel oil, carbon dioxide, or other byproducts may be credited against the costs when markets for such byproducts are available. The dried residues from the fermentation of various materials (except molasses) have values which differ for each raw material, and these values also fluctuate with demand and with the price of the original raw material. No fixed price can now be stated as being a true alcohol cost because of the influence of all these variables. Relative byproduct values may also decrease with the increase of production of alcohol to the required amounts for a national-blend program.

Perhaps 25 million additional acres of crops would be required for such a program above present acreages. Successful experimentation in producing larger alcohol returns per acre, through intensive planting or fertilization or through the use of special varieties of the respective source materials, may change present estimates as to crop requirements.

As far as can now be visualized, future alcohol costs can be so reduced as definitely to permit the use of crops as a future fuel source as petroleum prices advance. In this way, an annually renewable material resulting from the interaction of sun, air, soil, and water, may be economically available partially to offset consumption of present irreplacable fuels. Fuels may be producible by synthesis from gases at lower costs than from crop materials, but it is doubtful if fuels from shale oil or from the hydrogenation of coal can so compete.

Wood may be considered as an agricultural product, and alcohol can be produced therefrom. The cellulose of the wood can be converted into sugar by the action of mineral acids, and this sugar can be subsequently fermented to form alcohol. Two commercial processes are now in use in Germany, the Bergius process (employing concentrated hydrochloric acid), and the Scholler process (using dilute sulphuric acid, under different operating conditions). Yields of sugar seem to be somewhat similar in both processes. A considerable amount of byproducts results from the action of the acid on the pentosans and other hemicelluloses and lignin present in the original wood, and the utilization of these byproducts is essential for the commersial success of the processes. Pentosans yield unfermentable sugars which seem to have some value as stock feed. The lignin, however, which may constitute up to 30 percent of the original wood, still lacks much commercial utilization, being largely carbonized in the processes employing strong acid.

As an alternative, the wood could be burned for the production of carbon monoxide and hydrogen, and these gases might then be synthesized to form motor fuels by processes such as the Fisher-Tropsch, now operating in Germany.

Present wood resources of the United States would not be sufficient to carry a replacement fuel production program. Furthermore, annual acre returns would be low. Processes employing wood as raw material might also utilize the annual production of perhaps 200 million tons of cellulosic waste, such as cornstalks and cobs, straws, hulls, shells, stalks, etc., which now find relatively limited economic use. The inherent chemical composition of these materials is practically that of wood, with variation in the respective constituent percentages. These materials are comparable to wood waste, and all such materials, as well as low grade or inferior wood, might serve as sources of methanol, tars, oils, or of wood gas, if carbonized, in lieu of the wood saccharification processes mentioned above. Cellulosic materials are also direct potential sources of heat. Fuel compounds may also be synthesized from wood gases. Assuming low cost collection and processing of materials, a partial supply of replacement fuel might be produced from the utilization of such present forest or farm byproducts.

To consider the production of agricultural motor fuels as an expedient to create high crop prices will involve definite increases in fuel costs and a very extensive program of crop production, and a definite method of equalization of costs, standardization of blends, and sale of fuel would then have to be formulated in order to meet the changed economic conditions which would eventuate. Future advances of petroleum fuel prices resulting from approaching scarcity of reserves will tend to minimize the present differential between alcohol and petroleum.

From the foregoing, it should be apparent that the production of agricultural fuels involves not only technical questions but larger problems of national economics; and, therefore, a definite policy should be decided upon before embarking on an agricultural motor-fuel program. Casual or tentative excursions into such field, under present conditions, may not be economically successful because of the inherent problems which must be faced. Standardization of national motor fuel seems to be a prerequisite for success. The probable total increased fuel cost incurred through the use of a national alcohol blend would approximate, and might replace or offset, any national subsidies now being paid directly or indirectly under present crop-control programs. Use of agricultural fuels would permit the securing of a return from present crop wastes, which could be processed once the production facilities existed, and employment of labor would be stimulated and other indirect benefits secured.

There has been much controversy concerning the value of ethyl alcohol-gasoline blends in comparison with straight gasoline as fuel for internal-combustion engines. Since alcohol has only 84,425 British thermal units per gallon as compared with perhaps 135,000 for gasoline, the superiority of the straight petroleum fuel in this respect would be unquestioned if our present motors were designed to utilize efficiently the thermal capacity of the fuel, but this is not the case. Alcohol blends can be used under higher comparative compression ratios than ordinary gasoline, thus offsetting the need of employing tetraethyl lead or similar antiknock agents. Alcohol, itself, has an antiknock rating of 90 compared to iso-octane, which is the standard, while commercial motor gasolines range from 50 to 82 or more in octane rating, depending on source and method of production. The use of higher octane fuels under increased cylinder compression allows the generation of more power per explosion, and, therefore, under suitable conditions, an alcohol-blended fuel may produce equivalent power despite lower thermal value. The actual power and mileage output of an automobile engine is the result of such variables as compression, carburetor setting, spark adjustment, temperature, volatility of fuel, rate of forward motion, and engine and body design. The actual results are usually complicated by traffic conditions, methods of driving, head or tail winds, tire traction, road composition and grade, weight of car, and other variable factors. Since commercial gasolines are themselves not standardized in composition, and since car manufacturers use different designs and sizes of engines, different carburetion systems, and degrees of compression covering a considerable range, the over-all power production from ordinary gasoline varies for the several makes of cars, as well as for the usual trade fuels. This variation between gasolines is probably as great as the difference which would result from the use of a 10-percent alcohol blend, and at most, the net mileage output of such a blend would probably be within 5 percent of that of a comparable gasoline.

Advocacy of a 10-percent blend represents an economic compromise rather than a scientific optimum. In the case of blends of 15–20 percent alcohol concentration, while improved antiknock quality and water tolerance are achieved, mileage decreases due to lowered heat value may become more marked. Furthermore, the production of blends of this concentration on any national scale is now beyond the realm of immediate possibility. At the other extreme, blends of around 2 percent would give practically no increased antiknock effect and involve a slightly lowered heat value, at the same time accomplishing but little petroleum conservation. Experience has shown that blends of 10 percent will function in present motor cars with practically the same efficiency as gasoline. Since with this amount some petroleum conservation might be achieved, since an extension of agricultural crop production sufficient to yield this amount of alcohol is possible with available acreage, this percent blend presents the more favorable possibility from all standpoints.

Use of alcohol induces cooler engine operation, which is an advantage under certain conditions, but may affect engine starting in cold weather. Alcohol blends also possibly exhibit less vapor locking tendency in warm weather. The addition of alcohol to straight gasolines of low octane rating tends to improve the fuel, whereby it can be sold at the price of a higher grade; although, in comparison to tetraethyl lead, by use of which the same effect may be secured, the cost for alcohol may average a cent or more higher per gallon of blend, for the same equivalent effect. There is little real evidence to support claims that alcohol blends may have a corrosive effect on an engine. Certain adverse effects of alcohol may result; these relate principally to the solvent action of the alcohol on rust and gum deposits in the fuel lines, action on shellac where direct contact may occur, and possible action on the body finish of the car in cases of accidental spillage. The latter two effects can be easily controlled and are not inherently serious. Stoppage of the fuel lines due to solvent action on accumulated rust will occur when the cars are shifted from gasoline to alcohol blends, since gasoline contains traces of water which forms rust deposits. However, once the system is cleaned, no further difficulty should be experienced. The action of denaturants which may be used with the alcohol cannot, of course, be predicted in advance.

Since motor fuel alcohol will have to be denatured, and since alcohol blends also require the presence of so-called "blending agents" in order to achieve a greater tolerance to water admixture, it may be possible to combine the function of a blending agent and of a denaturant in one substance or mixture of substances. Alcohol now used for blending with gasoline is usually relatively anhydrous; otherwise, if 95 percent alcohol (commercial grade) is used, an unstable mixture results which is easily separated upon the addition of traces of water under extremes of temperatures. The greater effective quantity of blending agents employed, the more nearly a 95 percent alcohol blend will approach the characteristics of an anhydrous alcohol blend. Since blending agents may lend advantageous characteristics to the fuel, it may later be proved that the necessity of using anhydrous alcohol might be avoided. Suitable blending agents such as acetone, butyl alcohol, amyl alcohol, etc., may be produced from agricultural materials.

Considered from the standpoint of over-all thermal efficiency, agricultural products may not be comparable with other fuel sources. The present total yield of gasoline from crude petroleum is perhaps 45 percent by volume, the remaining 55 percent representing fuel oil, lubricants, pitch or coke and gas, all of which have secondary fuel values. In the case of a bushel of corn weighing 56 pounds, of which perhaps 6 pounds represents moisture, the remaining 50 pounds will change, under fermentation, into approximately 15 pounds of alcohol and 15 pounds of carbon dioxide, plus small amounts of fusel oil or other byproducts, the residue representing protein and fiber. This latter has definite value as a stock feed. On a thermal basis, about 94 percent of the energy represented in the original carbohydrate, before fermentation, is found in the alcohol. In other fuels such as hydrogenated products from coal, consideration must be given to the processing fuel consumed in effecting the changes, decreasing the apparent efficiency.

PART THREE—SECTION I

COAL MINING WASTES AND THEIR PREVENTION

By George H. Ashley*

Coal-mining losses, as shown by studies made in 1922–23 for the United States Coal Fact Finding Commission, range from nothing to 50 percent or more.[1] Theoretically, all of this is wastage. Practically, it may be divided into three parts: (1) Wastage due to carelessness or technically poor methods of mining or subsequent handling, (2) coal of which the cost of recovery exceeds the average cost but which may be mined profitably if the margin of profit is not too low, (3) coal of which the cost of recovery exceeds any probable near future sales price.

By cost and sales price here is meant the total cost, including capital cost and taxes to the point of delivery to the consumer; and by net sales price the realization after deducting the cost of selling. Were the sales prices high enough all coal could be mined at a profit. Under such conditions any coal left in the mine or lost in transit would be wastage. In the last analysis what is avoidable loss, and therefore wastage, and what is unavoidable loss, is determined by the relation between the total cost and the net sales realization.

In this discussion, coals will be designated as competible or noncompetible, according as they can or cannot be mined at a profit. This will vary with conditions so that noncompetible coals today may be competible tomorrow, or vice versa.

It is true that the total cost and net realizations are subject to modification; total cost by better technical processes, better financing, and the correction of any unfair tax or other charges; and net sales realization by better classification of the coal to enable it to enter more varied markets, better preparation to secure a better price, and in other ways.[2] Coal losses due to failure to take advantage of all these betterments should logically be treated as wastage and are so treated in this discussion. Thus, in mining coal for steel making, if mining be confined to the low sulphur parts of the bed, while coal in other parts of the bed suitable for steam making is left in the mine, that is clearly wastage.

Low Cost Mining

The ideal low-cost mine would be one serving a base-load power plant immediately over the coal bed to be mined, in which the bed has a uniform thickness of 6 to 10 feet, has no partings or binders, has uniformly low sulphur and low ash throughout, has a strong roof and a firm floor that does not weaken when wet, has coal lying at a slight depth but deep enough so that mining does not disturb the surface, is not overlain by rivers, streams, railroads, or heavy buildings under which coal must be left for support, has gentle dips to facilitate haulage and drainage and has impervious layers in the upper roof to prevent the influx of surface waters.

High Cost of Mining

In contrast with these ideal conditions, the physical conditions commonly found which tend to increase the cost of mining or transportation and which, therefore, tend to high costs and to the loss of coal in the ground may be cataloged as follows:

Thin and overthick coal.—The commonest factor which leads to leaving coal in the ground is thinness of bed. The writer once estimated the amount of coal of several thicknesses in a given area (225 square miles).[3] This estimate showed 45 percent of the beds less than 2 feet thick (lower limit one foot); 20 percent between 2 and 3 feet, or 65 percent below 3 feet; 26 percent between 3 and 4 feet, or 91 percent below 4 feet; 7 percent between 4 and 5 feet, and 2 percent over 5 feet thick. When it is not possible to mine coal below 3 feet thick profitably, 65 percent of the coal in that area will be left in the ground. By contrast, in 1903 coal in a nearby area was being mined successfully down to 17 inches. Obviously, much coal that was then competible later became noncompetible.

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[1] *Report of the U. S. Coal Commission*, 1925, pt. I, pp. 187–191; pt. III, pp. 1841–1876. Detailed reports on coal losses prepared for the Commission were as a rule published by the several States involved: e. g., J. D. Sisler, *Bituminous Coal Losses and Mining Methods in Pennsylvania*; Geol. Surv., Pa., Bull. M–4, 1924; D. C. Ashmead, *Anthracite Losses and Reserves*, Geol. Surv., Pa., Bull. M–8, 1926; J. D. Sisler and C. A. Allen, *Coal Losses in Ohio*, Ohio State Univ. Experimental Sta. Bull. 29, and others.

[2] W. H. Voskuil, *The Competitive Position of Illinois Coals in the Illinois Coal-Market Area*; Ill. Geol. Surv. Bull. 63, 1936.

Gilbert Thiessen, *Coke from Illinois Coal*, Ill. Geol. Surv. Bull. 64, 1937.

T. W. Guy, *Growth of Coal Preparation in Smokeless Fields of West Virginia*, Am. Inst. of M. & M. Engs. Tech. Paper 437, 1931.

J. R. Campbell, *Mechanical Preparation of Pocahontas Coal*, Am. Inst. M. & M. Engs. Tech. Paper 363, 1930.

J. R. Campbell, *Cleaning Bituminous Coal*, Am. Inst. M. & M. Engs. Tech. Paper 117, 1928.

D. R. Mitchel, *Coal Preparation Problems in the Illinois Coal Fields*, Am. Inst. M. & M. Engs. Tech. Paper 362, 1930.

[3] G. H. Ashley, *Topographic and Geologic Atlas of Pennsylvania, No. 65, Punxsutawney Quadrangle*, 1926, p. 127.

Remember that the cost of mining a 2-foot bed of coal is almost double the cost of mining a 4- or 5-foot bed.[4] The formula for value according to thickness used by the United States Department of the Interior in valuing the public coal lands was derived by the inversion of the estimated mining cost which yielded figures as follows: 10 feet, 100; 8 feet, 96; 6 feet, 84; 4 feet, 64; 2 feet, 36.[5] As a result of these cost relations, coal of less than some determined thickness is left unmined. If areas of such thin coal are large enough to warrant mining at some future time, coal left in the ground at this time should not be charged to wastage. But thin coal left in the ground, of such limited extent or in parcels of such extent and shape that it will never pay for its recovery, must be charged to wastage.

Of larger moment than thinner parts of a bed left in mining are thin beds that might be mined profitably in conjunction with thicker beds if the price realization was a little higher, but which, left behind, can only be mined by themselves at much higher cost, to which will often be added the cost of dewatering the areas originally mined out. As a result much such coal will never be mined. The extent of coal left in the ground may be indicated by a single example. Jefferson County, Pa., is estimated to have had originally 3,334,900,000 tons of coal in beds of 18 inches or better. Up to 1927, 279,400,000 tons had been mined out or estimated to have been left in the mines, leaving 3,055,500,000 tons in the ground.[6] Yet production in this county has declined from 6,474,764 tons in 1903 to 2,298,106 tons in 1927, not because of any depression but because of gradual exhaustion of the most competible coal under conditions that existed, resulting in ghost towns and all that goes with such a decline in business.

In England and Europe, in order to obtain the greatest possible recovery of coal, as a rule all beds are mined simultaneously, even down to 8 inches,[7] the higher cost of mining the thin beds being offset by the lower cost of mining the thicker beds. Just as the cost of mining thin coal increases as the thickness decreases, so the cost of mining very thick coal likewise increases more or less with the thickness. This is due to the difficulties of handling, of timbering, and other technical elements.[8]

Unmined parts of beds.—One of the largest factors of loss in present day mining is that certain benches or other sections of the beds are left in the mines. Such benches or parts of beds are left for three reasons:

First, several inches to a foot or more of "roof coal" may be left to support the roof when it is poor. Most coal beds are overlain by shale, and in many mines this shale, when acted upon by the moisture of the air, tends to fall, either in thin layers, in flakes, or en masse, and if it is overlain within a few feet by sandstone, the shale below the sandstone not infrequently tends to drop down.[9] If the shale that tends to fall is of limited thickness, it may be taken down as mining proceeds (draw slate) and shoveled into worked out areas. If, however, it is thick and continues to fall indefinitely, it is a common practice to leave a layer of coal immediately under the roof to protect the roof from the action of the air. This layer may be only a few inches thick, often depending upon the presence of a smooth parting which makes the coal below separate easily from the coal left. This coal, if left in the mine, is commonly lost or wasted. In some types of mining, it may be left as mining is carried forward in narrow rooms and then recovered in the retreat mining.

The second reason for leaving benches of coal is that these are separated from the bench or benches being mined by partings or binders of clay, shale, or other rock, which must not only be mined but separated from the commercial coal before it is marketed.[10] If the parting is not thick, is firm, and easily separated, it may not add much to the cost of mining the separated bench of coal. If, however, the parting is thick in relation to the thickness of the bench to be recovered, or is soft so that it tends to mix with the mined coal from which it can be separated only with difficulty, or if the parting is "burned" to the coal, so that it is very difficult to separate from it, the presence of such a parting may increase the cost of the recovery of the bench of coal above or below the part being mined so far above the sales realization price as to prohibit its commercial recovery.

The third reason for leaving parts of beds in the mine is because they contain impurities or other undesirable characteristics which are injurious to the sale of, or lower the sales price of, the coal. This is especially true where coal is mined for special use, as in steel making, or where the unmined coal because of impurities or other undesirable characteristics would, if mixed with the rest of the coal, so lower its quality and value as to make it unsaleable or saleable only at a price that would eliminate profits. This source of loss is most frequent in the bottom coal.

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[4] H. M. Chance, "The Cost of Mining Coal," *Eng. & Mining Jour.*, May 29, 1909, pp. 1099–1101.

[5] G. O. Smith et al., *Classification of the Public Lands*, U. S. G. S. Bull. No. 537, 1913, p. 84.

[6] J. F. Reese & J. D. Sisler, *Bituminous Coal Fields of Pennsylvania*, pt. III, "Coal Resources," Geol. Surv., Pa., Bull. M-6, pt. III, p. 109, 1927.

[7] C. A. Fisher, *Depth and Minimum Thickness of Coal Beds as Limiting Factors in Valuation of Coal Lands*, U. S. G. S. Bull. 424, p. 56, 1910.

[8] Wm. Carlton, "Working Thick Coal Seams in Two Sections," *Mines and Minerals*, July 1902, 556; October 1902, p. 110.
Coal Age, August 21, 1915, p. 290.
R. W. McGraw, "Pillar Extraction in Thick Seams," *Coal Age*, vol. 12, p. 768, 1917.

[9] J. D. Sisler, *Bituminous Coal Losses*, Geol. Surv., Pa., Bull. M-4, pp. 67–68, 1924.

[10] G. O. Smith et al., *op. cit.*, pp. 70–71.

Pillar losses.—Formerly, in nearly all mines and still in many mining districts, the largest source of loss comes from coal left in pillars for the support of the roof and the higher strata.[11] In some districts where the floor is soft and narrow pillars tend to produce squeeze of the underclay which flows out into the rooms or entries, wide pillars must be left to protect the mine.[12] Otherwise, the thickness of the pillars left to support the roof depends upon the thickness and character of the overlying rocks and the strength of the coal. There have been districts in which half or more of the coal has been left in the mine as pillars. Modern mining methods, where the roof is suitable, tend toward long wall or panel systems. In the panel system, most of the coal is recovered in retreat. In both long wall and panel systems, the roof is allowed to fall as soon as the coal is recovered, and the overhead weight is transfererd from the pillars to the broken-down roof rocks.

Added to room and pillar losses are boundary line pillars or pillars left on the boundary lines that separate one mine from another, which may be in operation at the same time or at a later date. The purpose of these pillars is to protect the approaching working of the later mine from water or gas that may have accumulated in the older mine; or if the two mines are worked simultaneously, to prevent mine waters of one mine from being unloaded on the other. Where both mines are under the same ownership and being worked simultaneously, no barrier pillar may be necessary. In some States, the thickness of the barrier pillar is set by law, varying with the thickness of the bed.[13]

Special pillars.—In addition to room, entry and boundary pillars there is usually some loss of coal in pillars around oil and gas wells, under streams, buildings, railroads, or roads. In some areas these are very small and in others, as in the anthracite region of Pennsylvania, they are very large. The purpose of heavy pillars around oil and gas wells is obviously to support the strata carrying the well pipes and tubing which, if the strata settle, are likely to be broken and flood the mine with oil or gas. Also such pillars prevent oil or gas which might creep up outside the well from entering the mines. Pillars under buildings or other structures must not only furnish vertical support but must allow for transverse subsidence extending diagonally from the edge of the mined-out areas, so that the area of coal required to be left may be many times the area of the surface to be supported. Under such circumstances, it may be possible to remove part of the coal, possibly half of it, the coal being removed in narrow rooms or channels so as to leave ample pillars to support the roof.

Losses in Recovery, Preparation and Transportation

Aside from the coal left untouched in the mines and between mining areas, in some districts much coal is lost in mining, preparation, and transportation. Such losses as a rule are entirely preventable. Among the causes of loss here are: (*a*) Fine coal (bug dust) formed by mining machines in cutting the coal or in shot firing, which may not be recovered but left on the floor or shoveled into the gob; (*b*) coal sticking to impurities or binders left in the mine as those are thrown into the gob; (*c*) coal left in the mine where faulty conditions exist, as horse backs or clay veins; (*d*) coal left under or above cuts made by machines which do not cut exactly on the bottom of the coal or under the coal or under the roof; (*e*) coal left on the bottom due to inefficiency of mechanical loading; (*f*) overloading mine cars with subsequent spilling and loss in transit; (*g*) old, leaky mine cars which permit losses in transit or coal which is left behind after accidents in transit; (*h*) fine coal produced in crushing or screening which becomes mixed with floor earth and is thus lost; (*i*) coal attached to impurities separated in cleaning and sent to the waste pile; (*j*) coal losses in railroad transportation, in handling in wholesale yards, and in delivering (these losses may be very small at any one point but may sum up to from 3 to 6 percent of the coal mined); (*k*) premature abandonment of mines; (*l*) small unmined areas left behind squeezes, roof falls, or other hazards;[14] (*m*) coal gouged out by small mines opened on the outcrop and mined in such manner as to prevent subsequent recovery of the coal left.[15]

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[11] H. N. Eavenson, "Regulation of the Coal Industry," *Am. Inst. M. & M. Engs. Trans.*, vol. 119, p. 383, 1936.

G. S. Rice, A. C. Fieldner & F. G. Tryon, "Conservation of Coal Reserves," *Third World Power Conference*, Wash., D. C., sec. IV, paper 11 (preprint), pp. 19–20, 1936.

J. D. Sisler, "Economic Aspects of Coal Losses in Ohio, Pennsylvania, and West Virginia," *Am. Inst. M. & M. Engs. Trans.*, p. 201, 1931.

[12] G. H. Ashley, "Coal Deposits of Indiana," *op. cit.*, Indiana Dept. of Geol. and Nat. Res., 23d Annual Report, 1898, pp. 1444–1446.

[13] G. H. Ashley, *Barrier Pillar Legislation in Pennsylvania*, A. I. M. M. E., Tech. Paper 277, Class F, Coal and Coke, No. 30.

[14] "Report of Planning Committee for Mineral Policy," *National Resources Board, Report*, Dec. 1, 1934, p. 401.

G. H. Ashley, Testimony in Carter Coal Case, Supreme Court of U. S., Oct. term, 1935, No. 636, *Transcript of Record*, p. 535.

J. A. Garcia: *Ill. Geol. Surv. Coop. Min. Series, No. 33*, pp. 14–15.

Special Losses

In addition to the above general sources of loss, local conditions may lead to high local loss. In places, the Coal Measure rocks are broken by faults, with an upthrow or downthrow of a few feet or hundreds of feet, and part or all of such displaced coal may be left in the mine. Elsewhere, there are small areas which may be isolated between old sandstone filled channels cut in the coal just after it was deposited. Where the roof is normally shale, it may be replaced locally by sandstone laid down in channels in the roof shales, and under these sandstone roofs, the coal may tend to be crushed or be high in sulphur and so not fit for the normal market for the coal of that mine. Or the coal may have been subjected to horizontal stress and, in places, have been moved, the coal being crushed by this process and thickened, thus spoiling it for the market being served by that mine.[16]

Beds Lost Through Undermining

A loss that is seldom taken into account is the loss of whole beds of minable coal from a previous mining of thicker beds underlying them by only a short interval. Most coal fields contain many beds of coal in the same vertical section, often a score or more. It frequently happens that the thickest bed and, therefore, the one most likely to be mined first is overlain by one or more other beds at short intervals. These beds, if of minable thickness, are likely to be so broken and crushed by the settling of the rocks forming the roof of the thicker bed and the floor of the thinner bed that the overlying thin bed cannot be recovered at all or only at very great expense.

Closely related to these is the loss of beds that might be mined with financial success if mined at the same time that other thicker beds are being mined but that would not pay if mined by themselves. Thus, in England, beds down to 8 inches thick have been mined in conjunction with the mining of other beds, of course only when and where the sales price would cover the cost of mining the thinner bed. Where two or more beds are worked in conjunction, a single shaft with its hoisting machinery serves both of the beds (or all of the beds) as does much of the other equipment also. Likewise, if a number of beds are to be worked at the same time, the life of the operation may be largely extended, and superintendents and other salaried services may not need to be increased for the mining of the several beds over the mining of one bed.[17]

Coal Lost on Account of Depth

A depth of 600 feet or less makes little difference in mining cost, but beyond some such depth as that, greater depth begins to add appreciably to the cost of mining and to the tendency to leave coal in the ground. The added cost arises from (1) longer lift for coal and water which, in some mines, exceeds the weight of the coal lifted;[18] (2) heavier timbering necessary at greater depth; (3) heavier pillars that need to be left in the mine, especially barrier pillars; (4) greater tendency of the coal at greater depths to crack and spall or crush and so become mixed with earth and rock; (5) greater hazards to miners due to greater pressure upon the coal at such depths.

In some mines, these increasing costs may lead to the abandonment of the deeper coal, and as the mine is likely to fill up with water, the dewatering of the old mine is added to the other expenses that might prevent future attempts at recovery of the deeper coal, unless the quantity of coal is quite large. Very little coal mining has yet been done in this country below a depth of 2,000 feet. In European countries, depths of around 4,000 feet have been reached. In England, 2 to 6 feet of coal is mined at the Rams mine of the Pendleton Colliery at Manchester to a depth of 3,483 feet. At the Birthday mine in New South Wales, Australia, a 3-foot bed is being mined to a depth of 3,000 feet. In general, conservation measures have been carried to greater extremes in Europe and other foreign lands than in America. In many mines, all of the beds encountered by a shaft to the bottom of the coal measures are mined simultaneously.

Lack of Continuous Operation

A factor that is generally recognized as one of the largest cost factors in coal mining and, therefore, eventually an element in the extent to which the higher-cost coal can be mined is instability of operation. There are several costs that go on continuously, whether the mine operates or not, such as capital costs, costs of salaried employees, costs of keeping the mine dewatered and even keeping it ventilated to prevent action of air on the roof, and the cost of cleaning up the mine after even a few days of idleness. These taken together and applied to the per ton cost of the coal are doubled if the number of tons of coal mined is only half what the mine would produce operating normally. Therefore, any plans which may contribute toward a more stable operation of any or all mines will reduce the per ton cost of the coal and to that extent permit the mining of high-cost coal that must otherwise be left in the mine if it is to be operated with commercial success.

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[15] Newell I. Alford, *A. I. M. M. E. Transactions*, vol. 108, pp. 476–488.

[16] G. H. Ashley, "Coal Deposits of Indiana," *op. cit.*, pp. 58–61.

[17] C. A. Fisher, *op. cit.*, pp. 56–57.

[18] R. V. Norris, "Water Hoisting in Pennsylvania Anthracite Region," *A. I. M. M. E. Transactions*, 1903.

Prevention of Losses

From the preceding discussion, it appears that preventable coal losses are due to—(1) lack of proper methods and care in mining, preparation, and transportation of the coal, and (2) too low a margin between the total cost and net sales realization, which necessitates leaving high-cost-of-mining coal in the mines if all profit is not to be wiped out. Remember that the coal industry has been in the red for years. In 1928 the net deficit was $25,000,000. In 1929, a boom year, 1,437 bituminous coal companies reported a loss, and the industry as a whole ran behind $11,000,000.[19] Under these circumstances, even the smallest increase in cost adds to the hardships under which the industry is already laboring, unless an equal burden is added to competing industries.

Assuming that the natural laws of gravitation and of supply and demand will continue in the future as in the past and cannot be changed, the problem before us is what can the Government do—or undo of what has been done—in order to help the coal industry prevent the coal losses or waste at present prevailing? It can do one or all of five things: (1) Establish laws and inspection service to prevent coal wastage and promote conservation; (2) relieve coal of any unjust burden imposed by Government that today increases the cost of production and so leads to wastage; (3) equalize the burden that must be borne but that today may not bear equally on the coal miners of different areas or as between coal miners and those producing other sources of heat and power; (4) control the opening of new mines so that when the margin of profit reaches a point where a larger portion of the coal is conserved, the opening of unneeded new mines may not, through increased competition, tend to destroy that margin; (5) continue its scientific study of the problems of the coal industry as related to coal losses and their prevention.

Mining Regulations in the Interest of Conservation

All of the coal mining States today have laws regulating the mining of coal in the interest of the safety and health of the miners. In most States, these laws have long been in force and have become accepted as a permanent phase of the coal mining industry. In addition to these, the Federal Government, in leasing coal on Indian lands or public lands of the west, provides in the interest of conservation that certain rules must be followed in mining coal on such lands.[20] These rules are necessarily realistic; that is, they take account of existing conditions that effect sales prices and to that extent determine how far conservation efforts can go without wiping out profits. These examples, therefore, show what can be done successfully. To the extent that such regulations may increase the cost of mining and thus add to the necessary sales price, and so decrease the margin of profit, they handicap the marketing of coal in the open market against the competition of oil, gas, or water power. Such legislation should therefore be undertaken only after consideration of all the factors in the problem and, preferably, in connection with other legislation to be suggested.

Leveling up average recovery.—The first and simplest step that any government can take for the conservation of its soil is to pass laws requiring that all mines adapt methods in accord with the general practice of the mines having the best records of recovery. This might have three effects: (1) It would increase the recovery at some mines without increasing the cost; (2) it might increase the cost of mining so that some small companies would be less liable to undersell other companies, which demoralizes the market price, leading the other companies to cut their costs by leaving more coal in the ground; (3) it might prevent the opening of new mines or lead to the closing of some small mines operated by people with little or no capital and with little or no training in coal mining. As in other lines of business, no small part of the price difficulty comes from underselling by small producers and from shipments of unassigned coal which is likely to become distress coal.

Problems of general increase of recovery.—When the attempt is made to raise the recovery practice of the larger mines of a district, difficulty may be encountered in that the physical conditions differ so much from one district to another that a given set of rules might not affect one district, while another district would be put out of business.

Thus, a rule that where there are two beds of minable coal, not further apart than ten times the thickness of the upper bed, that bed must be mined first, would not affect the district in which there was only one minable bed of coal. However, if such a rule were applied in another district where there were two beds, the upper say three feet thick and the lower five feet thick, but only 25 feet apart, and the upper 3-foot bed had to be mined first, the realization price might not be high enough to cover the average cost for the two beds, and the district be put out of business.

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[19] *Statistics of Income:* U. S. Bureau of Internal Revenue.

[20] Department of the Interior: Operating regulations to govern coal mining methods and the safety and welfare of miners on leased land on the public domain, under the act of February 25, 1920.

Simultaneous mining of two beds of coal a short distance apart is often followed, mining of the upper bed keeping a little in advance of the lower bed and the coal of the upper bed being ramped down to the lower bed to be moved out of the mine.

Equalization of Coal Taxes

This problem should be studied from the angle of the relative burden placed by Government on coal mining as between different areas—States, counties, or countries—and as between coal and other sources of heat and power. At the present time, coal is subject to the following Government-imposed cost items: (1) Land taxes, or if the mineral estate has been separated, tax on the estimated value of the coal in the ground, (2) the cost of carrying out safety measures required by law, (3) the cost of carrying workmen's compensation and old age assessments, (4) a sales tax on coal as sold (not universal), (5) job insurance taxes, (6) assessments for the conduct of the Guffey Act, (7) Government determined railroad and shipping rates. It is assumed from the start that items 2 to 6 must continue to be met, and while they are a subject for study, the tendency seems to be toward increasing the cost of those items, rather than to decreasing it. Items 1 and 7, however, are open for further consideration.

One of the cardinal principles of conservation is that it is wastage to use a less abundant or more valuable product when a more abundant or less valuable product is available. Comparing oil and gas and coal, there is no question but that oil and gas are more valuable and less abundant than coal. Conservation, therefore, in the broad sense should encourage the use of coal wherever possible as against the use of oil and gas, even though the latter may be more convenient. The question has been raised whether in matters of general taxation, taxes against coal, oil, and gas, etc., should not be so placed as to favor the use of coal rather than the reverse, and of low-rank or grade coal over higher-grade coal.

At present, coal lands or coal in the ground where the surface and mineral estates have been separated are subject to county and other taxes along with all other real estate. Oil and gas, because of the uncertainties involved, usually are not so taxed. In some areas a severance tax, in lieu of land taxes, is applied to oil and gas at the time they are recovered. No logical objection could be raised to either of these proceedings provided the taxes so laid are uniform and fair as between one area and another, or between one fuel and another. As matters stand, assessments often vary on the same bed of coal from one county to another and from one State to another; and assessments as between coal and oil may take little or no account of their relative value. Seldom do assessments take account of the factors that determine the value of coal lands when sold voluntarily between informed persons or corporations.

As a rule such sales involve only the best coal lands, so situated that the coal can be mined in the near future. To apply such sales prices as a basis of assessments on coal in general, without allowing for the physical circumstances that may prevail, as when no coal will be mined from certain lands for a long time, is likely to result in excessive capital cost for the coal when mined. The payment of such taxes yearly, regardless of how much coal is mined, or if none at all is mined, puts a burden on the operators that is too often met by leaving high-cost-of-mining coal under ground.

It has long been held that a fairer way to tax coal is to levy a severance tax to be paid when the coal is recovered. If such a tax is laid on all coal, oil, and gas as removed from the ground, and if at the same time the tax be on a sliding scale inversely proportional to the use value of the coal, oil, or gas, tax burdens would not penalize one product over another or one area over another.

It is therefore recommended that efforts be made to substitute a severance tax on oil, gas, and coal for the present state and county taxes, to be so graded as to represent as nearly as possible an equal tax, based on a fair average net realization for any district. To accomplish such a change in the method of taxation and to carry it out after the charge is made would seem to demand in interstate compact to be approved by Congress under act 1, section 10, part 3, of the Constitution of the United States.

Legislation to include oil and gas.—Legislation to be effective without so handicapping the coal industry as to put it out of business must take into account all of the factors involved, including the possible changing of laws or practices affecting the production of competing fuels and water power.

As part of a general plan, the State might be justified in putting special taxes on oil and gas now used as fuel, first, to conserve those fuels by reducing their fuel use in view of their wider adaptability than coal to many other uses and their lesser amount; and second, to permit coal to sell at a price that will cover the higher cost of mining the coal more thoroughly. Or, if the taxes derived from oil and gas used as fuel were used as a bonus to cover the greater cost of the higher recovery of coal, the general price of coal would not need to be so high as above suggested, nor the taxes on the oil and gas so high, in order to secure a high coal recovery. Such a plan would have a third advantage. If the price of coal is raised uniformly, some mines, having naturally favorably conditions both for low-cost mining and the percentage of recovery, might have too high a margin of profit at the expense of everybody. The bonus plan for the high cost of mining (at the expense of oil and gas users) would finance the higher cost of a larger recovery without boosting the price on either coal, oil, or gas as much as under the first plan.

Public Ownership of Coal as a Conservation Policy

Many people have felt that the coal, oil, and gas deposits of a State should belong to the State, which would then lease them to individuals and companies for mining operations. There have been five principal reasons advanced for this policy.[21]

1. The holding of large areas of reserve coal lands for future mining is a practice almost universally followed by the larger and stronger companies, and it involves a very large capital cost in both interest and taxes which must be assessed against the coal as mined and, therefore, results in less conservative methods of mining. Since the State can, as a rule, borrow money at much lower rates than any individual or company, the State can carry such a burden more easily than anyone else, thus relieving the industry of a large item of expense that today must be added to the cost of mining coal and, to that extent, effecting the amount of coal-mining losses.

2. If the unmined deposits of coal, oil, and gas are in possession of the State government, it can more readily control the methods of mining in the interest of conservation, especially in refusing to license new mines when such new mines are not needed and, if opened, would tend to upset satisfactory margins of profit when once attained.

3. There has long been a widespread belief that the State, rather than a few individuals, should profit from any increase in the value of the State's natural resources, especially its mineral reserves which are of limited extent and once exhausted, stay exhausted.

4. One of the strongest arguments in favor of public ownership of coal, oil, and gas lands at present is the large obstacle to efficient mining encountered in diverse ownership of the coal, except where it is possible for one company to get complete control of a deposit to the limits naturally favorable to unit mining operation. Where the coal is owned as a unit, it is possible to lay out mining areas to the greatest advantage, so as to avoid large coal losses from barrier pillars, from irregular land corners, etc. Again, it is usually true that mining losses are higher in smaller operations than in larger ones, ranging from the country bank operator who gouges out his coal from the outcrop for his own and his neighbors' use without any plan, to the large companies who pre-plan all their operations and carry them forward under adequate supervision.

5. Where the title of all of the coal is in the Government, it is conceivable that the Government would step in to meet certain extraordinary expenses, in order to realize on its investment, and to secure as much of its resources as possible. Thus, in one district, a large or long drainage tunnel might be necessary or desirable to recover all of the coal, but the initial cost of such a drainage tunnel might be beyond the resources of any or all of the companies operating in that district at the time or in the future. If mines were flooded by a greater than normal flood, it would be a good reason for the State to step in and pump out the mines, not only to recover the value of its latent resources but to put or keep men at work and the industry going.

The proposal is presented without comment, except to note that such a plan, if carried out, would greatly strengthen the State's hands in its attempt to conserve its fuel resources. The method usually proposed for putting such a program into operation involves a small tonnage tax on the coal as mined. Such a proposal is not new and, as shown on previous efforts to pass such legislation, gives rise to many objections. The point should be stressed that if the coal industry is relieved of part of the cost of carrying large future reserves, it will be in a better position to accept some increased costs in the interest of conservation. That is especially true if the plan is made universal and the tax handicap between one area and another is leveled off.

Technology of Conservation in Mining

Assuming that through whatever means may be employed, adequate returns on mined coal have been provided, what is necessary to secure as nearly complete recovery of the coal in the ground as possible?

1. Adequate capital. Inadequate capital is one source of coal losses. High-recovery mining, preparation, and distribution usually involve a large initial capital investment. If all beds are to be worked simultaneously the whole series may have to be shafted through at the start, or shafting may be extended as mining progresses. Again, if retreat mining is planned, haulage ways should be extended to the coal boundaries before

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[21] Frank Haas, "Stabilization of Credit and Operation of the Coal Industry," *Mining & Metallurgy*, p. 81, 1936.
Geo. S. Rice: *Mining & Metallurgy*, p. 102, 1931.
Senate bill 1417, 74th Cong., 1st sess., January 21, 1935.

mining begins, adding to the initial outlay. Adequate prospecting and planning cost money.

2. Adequate knowledge of field. Adequate knowledge of the field is necessary if future mining is to be adequately planned. It is often customary today to drill only to the one bed which it is planned to mine. In the interest of conservation, there should be equal knowledge of all beds.

3. Adequate planning. Adequate planning should take account of and plan for the recovery of all coal under the ground, even though much of the coal may not be reached for a long time. Under the conditions here assumed as to adequate profits, plans should be made—if not for the simultaneous mining of the coal—for mining groups of beds from the top downward so that, as in Europe, the low cost of mining the thicker beds will compensate for the higher cost of mining the thinner beds. It may be that such plans cannot be put into practice until the decline in the reserves of oil and gas removes competition from that source. Initial plans should cover not only the removal of the coal, but water removal and other factors. In English mines, some of which extend to great depths, provision is made for the accumulation and removal of as much of the water as possible at the highest possible level. If such plans are made and carried out, one large item of expense for deep mining may be avoided or greatly lessened. Adequate planning involves adequate engineering knowledge and service.

4. Adequate area. It is possible to conceive of mining being undertaken in an area so narrow or otherwise limited that half of the coal must, under the law, be left in barrier pillars. Again, it may cost as much to sink a 500-foot shaft to mine out 200 acres of land as to mine out 2,000 acres, but the charge against the coal is ten times as much in the first instance as in the second. This is also true of other costs. On the other hand, as a mine is extended, it reaches a point where increased cost of haulage, ventilation, transportation of men and materials point to the opening of a new mine from which the coal beyond is to be reached, as more efficient than extending the old mine. In the interest of conservation, the area mined at the opening should, when possible, be large enough to warrant the necessary initial expenditures and operating costs, without being so large that the carrying charges on reserve coal would offset the other savings.

5. It is not possible to lay down hard and fast rules as to what method of mining is best for any area. Differences of roof, floor, bed section, selective mining of benches, or other factors may determine what is the best method for a particular bed, or even part of a bed. It is assumed that where feasible stripping will be employed. That yields, theoretically, 100 percent recovery. Steeply dipping beds require different methods than level-lying beds. The introduction of new equipment may lead to new methods more efficient than the old. The main point is that with adequate engineering and technical service the best available method be adopted and adhered to, subject to change if conditions change.

6. A practice that helps where applied is to charge royalty, not on the tonnage recovered, but on the original tonnage in the bed; payment being made on the estimated tonnage per acre mined out. Other penalties for coal left in the bed that reasonably should be recovered would make its recovery more likely.

Transportation

A final factor over which Government has some measure of control is that of transportation costs. Price competition between coal, oil, and gas is at the point of consumption. If, as is often true, freight charges on coal exceed mining costs, they certainly deserve careful consideration as a factor in conservation. In 1897 the writer made a study of the economic possibilities of transporting, from the coal fields to the points of consumption, energy from coal in the form of gas made at the mine.[22] Without going into details, as rail transportation of coal averaged at that time about one-half cent per ton-mile, it appeared that, at that rate, rail transportation was cheaper than piping the same energy as gas. With the changes of the last 40 years, the relative costs may be different today. Great progress has been made in electrical transmission of energy, but such transmission still suffers from the low efficiency of the steam engine. For short distances, a few miles, rubber belts are being used successfully. Truck haulage has replaced considerable railroad transportation, though opinions differ as to the relative cost for different distances. Many coal men believe that considering that coal is commonly delivered to the railroad and taken away, often in trainloads, without charge for loading or unloading, the rates charged are out of line with charges for other kinds of freight. Such questions only add to the need for study of the whole matter, which is of vital importance in a program for better conservation of coal.

In the meantime, considerable progress has been made in short circuiting the transportation problem by bringing power and industrial plants to the coal mines. Assuming that part of the saving can be used to meet the higher cost of more complete recovery, such a bringing together of fuel and power needs should be a measurable factor in securing a larger recovery of coal.

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[22] G. H. Ashley, "Coal Deposits of Indiana," *op. cit.*, pp. 1552, etc.

PART THREE—SECTION II

PHASES OF TECHNOLOGY IN THE PETROLEUM INDUSTRY

By R. A. Cattell,[1] H. C. Fowler,[2] and A. J. Kraemer[3]

The progress of the petroleum industry, broadly including the natural-gas industry, depends upon the feasibility of its technical procedure. Every department, from exploration for new sources of supply to distribution of products for final use, has shared in the benefits of evolutionary attainments. The forces stimulating advancement and the economic significance of various developments and improvements have been treated in an earlier section.[4] Accordingly, this discussion is limited to brief sketches of some of the more important developments in methods and processes now used by the petroleum industry.

Exploration

No longer is dependence placed entirely upon surface indications, such as oil seepages and bubbling gas, to suggest likely places to drill in search of possible underlying oil-bearing formations. The science of petroleum exploration had a difficult beginning. Although White,[5] in June 1882, "discovered anew the neglected and forgotten 'anticlinal theory' of Hunt, Andrews, and Hoeffer, which he vitalized and regenerated for all time" and later published his thesis in Science for June 26, 1885, it was after 1900 that the industry finally began to look upon geology as a definite aid in finding oil.[6]

However, during that interim the geologists themselves were carefully acquiring knowledge of structures and deformations in the earth's crust. Instruments such as the plane table and alidade (a combination of surveying transit and drafting device used for mapping in the field) were of great aid in determining the positions of "marker" or "key" beds exposed at the surface. These and auxiliary equipment continue to be used in mapping surface geology. Following the lead of the United States Geological Survey, geologists soon recognized the advantages of showing domes, anticlines, and other geological features on maps by means of structure contours.

Ambrose[7] clearly marked certain limitations in correlating surface and underground geology when he said in part:

> The areal structure map serves as a valuable guide in predicting the attitude of the underground beds. Experience is showing more and more, however, that in flat-lying formations there is likely to be enough difference in the structure of various horizons to make inferences based on the structure of the surface or even of another horizon unsafe.

With this fact in mind, petroleum engineers and geologists were attempting to correlate underground formations on the basis of well logs, and by 1920 various kinds of cross-sections, sub-surface-contour maps, and peg-models in three dimensions were being used extensively in attempts to gain a better understanding of conditions underground. However, drilling logs frequently were found to be in error because bit cuttings could not be identified accurately on the derrick floor, and today geologic logs made with the aid of micropaleontology largely have supplanted the logs based on information supplied by drillers.

As more and more wells were drilled by the rotary method, it became evident that the "returns" of the circulating mud fluid failed to give adequate formation specimens for study. Even the samples obtained with the bailer in cable-tool drilling were unsatisfactory for the more exact examinations of the geologists and paleontologists. Increasing attention was given to careful coring to obtain samples of the rocks in a condition as nearly as possible like that in which they existed before being disturbed. This led to taking cores ahead of the drill with specially constructed core barrels.

In some areas the diamond drill has been used to determine the position of "marker" beds, and less frequently holes having diameters of 4 to 8 inches have been cored from surface to bottom, but no very deep oil wells have been bored with the diamond drill.[8]

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[2] Senior Petroleum Engineer, Petroleum and Natural Gas Division, Bureau of Mines.

[3] Senior Refinery Engineer, Petroleum and Natural Gas Division, Bureau of Mines.

[4] Pt. one, sec. II, ch. 3.

[5] White, I. C., "Important Epochs in the History of Petroleum and Natural Gas" (presidential address before the Geological Society of America, December 28, 1920), *Bull., Geol. Soc. Am.*, vol. 32, March 31, 1921, pp. 171–186.

[6] White, David, "Some Outstanding Features of Oil-Field Development in the United States, 1859–1934," printed as sec. 6 of "A Résumé of Geology and Occurrence of Petroleum in the United States by the United States Geological Survey;" *Hearings Before a Subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, on H. Res. 441, Petroleum Investigation, 1934,* pt. 2, pp. 884–895.

[7] Ambrose, A. W., *Underground Conditions in Oil Fields*, Bull. 195, Bureau of Mines, 1921, p. 67.

[8] Edson, Frank A., *Diamond Drilling with Special Reference to Oil-field Prospecting and Development*, Bull. 243, Bureau of Mines, 1926, 170 pp.

Coring and subsequent examination of the specimens are adjuncts of both the exploratory and extractive branches of the industry, and geologists and production engineers are equally concerned with the information that the various analyses of the core samples reveal—but for somewhat different reasons. Some of the first core barrels used in wells drilled by the rotary method in soft formations were improvised from sections of pipe with teeth cut in the lower end with a hack saw or cutting torch. After this crude barrel attached to the drill pipe was rotated slowly at the bottom of the hole, an increased weight of the drill pipe caused the teeth to be crimped, making a "basket" or core catcher, and the specimen was removed. Cores taken in this manner were not entirely satisfactory and were likely to be burned by heat generated by friction.

Many improved designs of core barrels soon came into wide use, and today cores are taken in the hardest sedimentary formations and even in igneous rock. Special bits have been designed that mill the rock and leave a solid core in the center. Cores are kept in good condition with maximum recovery by circulating the drilling fluid between the outer barrel and an inner barrel which retains the core. Some coring devices are constructed to permit removal of the core barrel and its retained core through the drill pipe with a wire line. This type of operation reduces the time required to take a core, because the drill pipe need not be removed from the hole.

Other coring devices take samples of the formation on the side of the hole, either parallel to or at an angle with the bedding plane of stratified rocks. Surveying instruments have been devised that permit cores to be oriented and their exact positions determined with respect to the formations from which they were taken. One type of coring device (known as a "biscuit cutter" because of the size and shape of the specimens) has been used extensively in regions still drilled with cable tools. Although 100 percent of the core is not obtained in perfect condition, these specimens give a great deal more material with which to work than the crushed cuttings of the percussion bit.

In a research project undertaken by the Federal Bureau of Mines, in cooperation with the American Petroleum Institute, the objective is to develop a core barrel that will take a sample of rock with its contained fluid from the formation at the bottom of a well and bring it to the surface without loss of pressure or contamination from the drilling fluid. Engineers and geologists believe that the use of such a device will result in a much wider knowledge of fluids (oil, gas, and water) in reservoir rocks.

The most radical change that has come about in exploring for oil and gas deposits has resulted from the introduction of instruments and methods used by physicists and seismologists in studying earthquakes. Their technology had to be modified and improved to meet field conditions. Although artificially excited elastic earth waves were applied to some extent in determining local geologic structures as early as 1913, it was not until 1921–1923 that the fieldworthiness of these instruments justified their practical use as an aid in petroleum exploration.[9] Despite the evolutionary effects of applied geophysical methods of oil and gas exploration, the science is imperfect, and interpretation of the results depends upon theory which is incomplete.[10]

Unfortunately, paralleling this view held by those well versed in the subject is a too prevalent optimism on the part of many persons who have had no occasion nor opportunity to become informed on the subject of seismic and other geophysical principles. These persons fail to differentiate between well-founded scientific methods of exploration and other purported ways of oil finding that seem to require some metaphysical or similar influence. In this category may be mentioned divining rods and kindred devices, some of which have the appearance of complicated mechanisms. No attempt is made in this paper to describe the equipment used in geophysical prospecting. The point to be kept in mind is that each method, requiring its own special apparatus, is based upon well-established physical principles; that the results are an aid to, rather than a replacement of, interpretations based upon geological evidence; and that these instruments and methods are useless and obscure to those who have no foundation in the science and only vaguely appreciate the objectives.

Seismic methods used to determine the position and shape of underground structures where oil and gas may have been trapped during geologic time are employed more widely than any of the other recognized methods of geophysical prospecting. Until about 1926 the refraction type of seismograph was used almost entirely. In this method scientific use is made of the fact that seismic or earth waves caused by a charge of explosive detonated at or near the surface will travel with greater speed through dense rocks (such as those composing salt domes) than through the surface formations between the blast and the recording device.

The less expensive reflection method of recording and interpreting artificial seismic waves now is used by virtually all companies. In the reflection method the depth and configuration of deeply buried beds are determined from records of waves that originate at the blast and are reflected back to the surface, similar to the echoes that result from reflection of sound waves.

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[9] Barton, Donald C., "The Seismic Method of Mapping Geologic Structures," *Geophysical Prospecting, 1929*, Amer. Inst. Min. and Met. Engrs., pp. 572–624.

[10] Heald, K. C., "The Technique of Exploration," *Technology and the Mineral Industries*, Works Progress Administration, National Research Project in cooperation with the Bureau of Mines; Mineral Technology and Output-per-Man Studies, Report No. E–1, April 1937, p. 8.

In recent years seismic methods of exploration have been applied to submerged areas where evidences of surface geology are meager or entirely lacking; thus a wide field for exploratory work has been opened throughout the Gulf coast area, where tidal waters and tributaries range in depth from a few inches to 15 feet or more. Transportation may be by boat or barge where the depth of water permits, but vehicles known as "marsh buggies" have made possible exploratory work in many otherwise impenetrable places. Because of the buoyancy and mechanical construction of these marsh buggies which serve the purposes of both motor vehicle and motor boat, the exploring parties can travel in them on land, through marsh, or over water.

Although not as widely used as seismic methods, several other means of geophysical exploration have their peculiar advantages. Among these may be listed methods and apparatus for measuring (1) magnetic phenomena in the earth's crust caused by certain mineral deposits, (2) variations in rock density and other factors that cause local changes in the gravitational forces, and (3) the conductivity or resistivity and other electrical properties of rocks constituting the earth's crust.[11]

An electrical method that is used more extensively in determining the characteristics of rocks surrounding a well than in establishing the existence and limits of geologic structures is commonly referred to as electrical logging.[12] Like mechanical coring, electrical logging can be applied widely to solve problems in drilling and production as well as those in geology. This art was introduced into the United States in 1932, but it has been used in Russia and Venezuela since 1929. Few progressive operators will drill a well today in regions where underground conditions are complex without using some form of electrical logging, the results of which sometimes give information concerning subsurface conditions that can not be obtained by analyzing cores or any other method of studying the characteristics of reservoir rocks.

Rocks transmit electric current by reason of absorbed water that contains dissolved salts. The conductivity of the rock increases with the concentration of the electrolyte. Making use of these and other scientific facts, the electrical resistivity of the rock (the reciprocal of the conductivity) is measured with recording mechanisms connected to an electrical circuit, one terminal of which is an electrode that is run into the bore hole; the other terminal consists of suitably placed grounding rods at the surface. Information in addition to the resistivity of the rocks is obtained. For example, it is possible to detect porous rocks in contrast with those having impervious characteristics. The electrical log does not show the actual porosity or open spaces in the rock, but the so-called "porosity" logs as determined electrically can be correlated with similar records taken in adjacent wells on the basis of relative ability to hold oil in the pore spaces. Electrical methods also are used by production engineers in determining points at which water enters wells and in evaluating other reservoir conditions.

Recently considerable interest has been evidenced in this country regarding certain chemical methods of determining minute quantities of hydrocarbon substances (especially ethane) in soils as a possible indication of petroleum structure. The Russian literature on this subject (several articles have been translated into English) is more extensive than that of this country.[13] The theory back of this inadequately developed technique is that micro quantities of gas escaping during geologic time through fissures and fractures from underlying petroleum reservoirs may be retained by the soil. According to Eby,[14] "These fractures or fissures tend to be sealed over the top of the structure, so that the leakage that takes place is concentrated around the edges of the mineralized zone in the form of a ring, or halo." The usual methods of gas analysis are not applicable for determining such minute quantities of ethane, which may range from 0 to 200 parts per billion by weight of the soil. Chemists are attempting to develop a technique on a fundamental basis, and if their efforts prove successful, another means may be available for defining the limits of areas for further exploratory work.

As the more pronounced structural traps for oil and gas, such as anticlines and domes, are found and explored with the drill, search is being extended to areas where geologic conditions make stratigraphic accumulations possible.[15] An outstanding example of stratigraphic accumulation is the East Texas field, concerning which so much has been written in the technical press and newspapers. However, a list of 22 major fields in the United States includes at least 9 in which oil and gas are said to have been trapped because of changes from porous to nonporous rock material. In exploring for these types of petroleum deposits portable machines capable of drilling small-diameter holes to depths of 6 to 8 thousand feet are being used.[16] Lahee[17] has pointed out advantages of drilling holes of small diameter that may be tested with electrical-logging and side-wall sampling devices, which if warranted, later can be conditioned for production.

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[11] Eve, A. S., and Keys, D. A., *Geophysical Methods of Prospecting (A brief and elementary account of the principles involved)*, Tech. Paper 420, Bureau of Mines 1927, 26 pp.

[12] Schlumberger, C. & M., and Leonardon, E. G., *Electrical Coring; A Method of Determining Bottom-Hole Data by Electrical Measurements*, Tech. Pub. No. 426, Amer. Inst. Min. & Met. Engrs., 1932, 38 pp.

Deussen, Alexander, and Leonardon, E. G., "Electrical Exploration of Drill Holes," *Drilling and Production Practice, 1935*, Amer. Pet. Inst., pp. 47–59.

[13] Eby, J. Brian, "Newer Trends and Methods in Geophysical Petroleum Exploration," *Pet. Eng.*, Mid-Year 1938, pp. 31–40.

Bignell, L. G. E., "Exploration for New Oil Fields Stimulated by Soil Analysis," *Oil and Gas Jour.*, July 28, 1938, pp. 69–70.

[14] Eby, J. Brian, work cited, p. 38.

[15] Levorsen, A. I., *Stratigraphic vs. Structural Accumulation*, Bull. Am. Assoc. Pet. Geol., May 1936, pp. 521–530.

Even a listing of all the exploratory methods that have come to the foreground in recent years would be impracticable. As suggested, many of these methods and devices play as important a part of the technique of drilling and production as in exploratory work. In fact, a well being drilled in unproved territory may be considered as an assembly of equipment for exploratory purposes until the existence of a commercial deposit is proved.

Formerly the productivity of a formation was tested by bailing the well, or the mud fluid was removed by swabbing or by flowing the well directly into the mud pits if the pressure was great enough. Modern technique has devised a way to test formations through the drill pipe—known as "drill-stem" testing. In this method the drill stem is fitted with a packer that is forced tightly against the walls of the hole just above the formation to be tested. Proper manipulations of the drill stem open and close a valve with which the packing device is equipped. If present in the formation, fluid will enter the drill stem and flow to the surface when the valve is opened—provided there is enough pressure. Information thus obtained permits the operator to decide whether to complete the well or continue drilling. This method of testing greatly reduces the hazard that a well may get out of control if the pressure in the formation is high. It is faster and more economical than the older methods, and the producing characteristics of the well can be determined with greater certainty.

Another device that probably is used more extensively in production work than in exploratory operations is the gun perforator. This mechanism shoots bullets through the casing at any desired depth. The charge of powder is detonated electrically, and the gun is designed to produce a high muzzle velocity despite the short length of the smooth barrel. The steel bullets, by penetrating the casing and surrounding rock, provide channels through which oil and gas will flow into the well if the formation is productive. Modifications have been made in these gun perforators for obtaining side-wall samples in uncased portions of the hole. The bullets for this purpose are hollow cylinders attached to the gun mechanism with flexible springs. After being shot into the formation the bullets can be retracted and brought to the surface where the contained cores are examined.[18]

Photographs have been used for a long time by geologists as an aid in describing structural features, but aerial photography as applied to mapping has developed into a method of geological exploration that includes far more than merely taking pictures from the air. Eliel[19] has summarized the circumstances in the statement, "* * * the airplane carrying its mapping camera is a superb reconnaissance tool, only awaiting his (the geologist's) ingenuity in correlating the pictures with the ground to simplify most exploratory problems."

Nearly everyone has some acquaintance with photographs taken from the air and probably has seen mosaic maps on which prominent features of terrain are plainly visible. Few persons, however, appreciate the technique and equipment that has been developed for air and laboratory use since the relatively crude beginnings of a wartime necessity. Today aerial photography is on a scientific basis, permitting exact engineering calculations.[20] Aerial maps can be made with a contour interval of 5 feet. This is equal to the accuracy of many transit or plane-table surveys made with stadia readings, and many geologic features such as anticlines, synclines, and faults that are clearly discernible on aerial maps can not be seen from the ground. However, the need for detailed ground surveys at likely places is not obviated.

An instrument that has done much to solve the problem of photographing long parallel strips has been devised to aid the pilot in flying a predetermined course with minimum deviation from a straight line. Improved laboratory methods of assembling and placing the mosaics have added to the accuracy and speed of map making from the air.

Heald[21] has summed up the situation regarding exploration for oil and gas aptly in stating: "It is believed that the intensive geologic attack, aided by an aggressive technology, may reveal new types of mineral deposits and that the geophysical attack will reveal mineral resources that can not be discovered by existing methods."

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[16] Bignell, L. G. E., "Deep Wells to be Drilled to Secure Subsurface Data," *Oil and Gas Jour.*, March 11, 1937, pp. 46, 49, 55.

Mills, Brad, and Taylor, Frank B., "Small Hole Drilling Holds Wide Possibilities," *Oil Weekly*, August 8 and August 15, 1938, pp. 22–28 and 26–31, respectively.

[17] Lahee, Frederick H., "Wildcat Drilling in 1937," presented before the Am. Assoc. Petrol. Geol., 23d Annual Meeting, March 1938; see *Oil and Gas Jour.*, March 17, 1938, p. 41.

[18] Leonardon, Eugene G., and McCann, D. C., *Exploring Drill Holes by Sample taking Bullets*, Tech. Pub. No. 1062, Am. Inst. Min. and Met. Engrs. (New York meeting, February 1939, 13 pp.).

[19] Eliel, Leon T., *Aerial Reconnaissance and Contour Mapping in Mining*, Tech. Pub. No. 756, Am. Inst. Min. and Met. Engrs., 1936, p. 4

[20] Meyer, Wm. H., Jr., *Development of Aerial Photographic Equipment*, Tech. Pub. No. 756, Am. Inst. Min. and Met. Engrs., 1936, pp. 21–27.

[21] Heald, K. C., work cited, p. 10.

Drilling

The first oil well was drilled to a depth of 69 feet after months of harrassing difficulty with tools and technique patterned after those used in the salt-brine industry. The bottom of the deepest hole that has been drilled (1938) is 15,004 feet below the surface of the earth—nearly 3 miles. These comparative depths roughly measure the changes in drilling technique that have taken place during the 80 years of the petroleum industry. Many volumes have been written in attempts to tell the complete story of how these changed conditions have been brought about. Only a few outstanding items can be mentioned in this paper.

The equipment of the pioneer drillers was fashioned largely from wood, and the metal parts were forged by blacksmiths in accordance with their own ideas of what was required. The first wells, some of which were drilled with improvised spring poles—the principle of which is not far removed from that used by the Chinese centuries ago—resulted from the chipping action of a repeatedly falling chisel-nosed bit. In the percussion method, later known as the "cable-tool" method, the bit is actuated by a rope or cable attached to a walking beam at the surface. The steam boilers and engines of the period were crude and inefficient and many operations on the derrick floor were manually laborious—such as "tromping the bullwheels" by hand and foot to bail out the cuttings and perform other lowering and hoisting operations. Later the two bullwheels, joined by a shaft, were mounted on the side of the derrick opposite the engine and connected indirectly with it by means of bull ropes. These endless ropes run in grooves on one of the wheels and can be thrown from it as required. The rim of the other wheel is used as a braking surface. The bullwheel shaft is used to spool the drilling line, and a calfwheel with its shaft (a later addition) handles the casing lines. Another addition is a sand reel, upon which a line of smaller diameter than the drilling line is spooled. This sand line lowers and hoists the bailer and greatly decreases the time required for bailing wells.[22]

The general adoption of rotary drilling marked a turning point in the history of the industry toward deeper producing formations with attending higher pressures and temperatures in the reservoirs and many new engineering problems. The rotary method, which in simplest terms may be likened to the boring of a hole with an auger, was initiated about 1900. The innovation proved successful in penetrating the soft, unconsolidated strata found in the Spindletop, Tex., and other Gulf-coast fields. The rotary method gained in favor, and many new features were added during the development of fields in California, where it was quickly adopted. With the development of cone and roller rock bits that grind or mill the formations, instead of cutting them as with the conventional rotary bit shaped like a fishtail, operators found it possible to drill hard, consolidated formations. Another innovation used by some operators to drill through relatively soft formations is a collapsible rotary bit that may be inserted and retracted through the drill pipe by means of a wire line, thus reducing the "down time" for changing a bit because the drill pipe remains in the hole. The overall result of the many improvements has been that the cable-tool method is being used less and less, except for portable or semiportable outfits suited for shallow drilling and for the drilling of certain cavernous limestones where loss of drilling fluid to the formations might cause major operating difficulties.

The mind does not have to be taken back to the pioneer period to be given some startling comparisons. Pictures of derrick floors taken 20 years ago evoke comment regarding their inadequacy compared with present operations that have made deep drilling possible. However, the need for going to the deeper horizons in 1919 and 1920 was not as urgent as today.

Designers, structural engineers, and all those concerned with the drilling of wells to greater and greater depths would have been helpless without the aid of metallurgists and chemists. In the metallurgical field, studies of mixtures of molten metals and their subsequent cooling, rolling, shaping, and heat treatment, and the facing of cutting surfaces with hard metals and alloys, have made many of the present attainments possible. With superior alloy steels of high-tensile strength available, it is now possible to manufacture and fabricate tools, rig parts, pipe, and machinery that permit larger design, withstand greater shock and impact, and meet requirements of toughness, hardness, ductility, resistance to fatigue and corrosion, and have better welding properties.

Uren and Jeffrey[23] have described the main operations of rotary drilling in detail. Bell[24] has reviewed outstanding new developments in equipment and methods that pertain to the present technique of drilling deep wells. Mechanical equipment at modern derricks is so involved and includes so many items that reference to Bell's article is recommended because the descriptions are brief but explicit, and the halftone illustrations and line drawings that accompany his article clarify many features that can not be well described in words.

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[22] For complete descriptions of churn-drilling equipment and methods see: Uren, Lester Charles, *Petroleum Production Engineering,* "Oil Field Development," Second edition, 1934, Ch. VI, McGraw-Hill Book Co., New York.

Jeffery, Walter H., *Deep Well Drilling,* Third edition, chs. VIII and IX, Gulf Publishing Co., Houston, Tex.

[23] Uren, Lester Charles, work cited, ch. VII.

Jeffrey, Walter H., work cited, chs. III–IV.

[24] Bell, A. H., "Greater Tools—Greater Depths," *Petroleum World,* 1938 Annual Review, pp. 45–70.

Although steel derricks and requisite parts, such as various posts, supports, and walking beams had been designed prior to 1900, many drillers during the period of 1920–25 complained that steel derricks had no "give" when a load was placed on them and gave little or no warning before collapse. Despite this opposition to a newer order, the forests of wooden derricks once prevalent in oil-producing regions now are reminders of fields going into their declining producing lives. Many wooden derricks have been dismantled in these older fields and replaced with steel pumping derricks.

Drake's derrick was about 35 feet high, and 84-foot derricks were adequate for cable-tool drilling for many years. Today derricks reaching heights of 176–178 feet are not uncommon, and it is understood that a derrick has been designed that will extend more than 200 feet above the derrick floor. The substructures of the newer derricks are of steel and usually raise the floor 9 to 16 feet above the ground level. This permits massive gate valves and blow-out preventers to be placed without the inconvenience, hazard, and expense of deep cellars. The base of these tall derricks may be as large as 32 feet square, permitting ample working room and space to "rack" (stand on end) more than 2 miles of drill pipe in lengths or "stands" of 120–150 feet. This type of construction was not required when cable tools were in general use or even when maximum depths of rotary-drilled holes were between 5,000 and 6,000 feet.

Offshore or marine drilling has led to many innovations unthought of by the industry a few years ago. Some wells are drilled from piers or wharves, as in California, that extend into water that may be 40–50 feet deep. Caissons of concrete and steel are sunk into the sand of the ocean floor to permit the wells to be drilled and to protect them after completion.

Along the Gulf coast and in its bordering lagoons and bayous where the water is not over 12 or 14 feet deep, drilling barges are used. The completely erected derrick and all auxiliary equipment, including the power unit and mud-circulating system, are mounted on flat-bottomed, steel hulls that are braced securely with structural steel members, and towed to the desired location. Sometimes twin barges are fastened together as a single unit. The power barge containing the gasoline-electric or Diesel-electric generators usually is permitted to float throughout the drilling operation, but after being towed into position, the sea valves of the drilling barge (or barges) are opened, and the hull is filled with water. The barge sinks until the lower plates rest evenly on bottom, with the deck remaining a safe distance above the water line. The unit is lashed to piles, and drilling begins almost immediately after the derrick is plumbed.

Sometimes the drilling crews are quartered in a boathouse at the site. All material such as fuel, water, pipe, and cement is brought by tenders towed by tugboats. Cementing trucks and other service outfits reach the well by means of boats or tenders. Extreme care must be taken against spilling oil or any other material that may be harmful to the body of water surrounding the drilling operation. After the well is drilled and protected against accident (a network of piles and cribbing usually is erected around and over the wellhead), the drilling barge is raised by pumping water out of the hull, and the complete unit is towed to the next location. A well has been completed, the barges moved to a new location, and the new well started within 14 hours. The initial cost of the outfit is much greater than that of equipment required to drill holes of similar depth on dry land, but once equipped, one barge may be used to drill many wells with only a relatively short "down time" for moving.

The satisfactory circulation of drilling fluid is essential to successful rotary drilling. Drilling fluid serves the following main functions: It cools and lubricates the bit, removes drill cuttings from the hole, plasters the walls of the hole, and otherwise prevents them from sloughing or caving, prevents fluids from migrating from one stratum to another, and because of its weight keeps the great pressures of oil and gas in the natural reservoir under control.

Little attention was given to the characteristics of the circulating fluid in the first wells drilled by the rotary method. The water was thickened with clay available at the site or penetrated in the upper formations, and the mud was maintained at a fluidity that would not cause difficulty or stoppage in pumping. Some of the first writings of the Bureau of Mines on petroleum treated the subject of mud-laden fluid as a means of preventing waste of oil and gas from flowing wells.[25] From this initial engineering approach, a new technique developed with respect to drilling fluids, and the whole science of plastics and plastic flow is now of major concern to the industry. The importance of this subject is indicated by some recently-prepared notes on the literature of drilling-fluids that include references to more than 200 technical articles. The science has gone much farther than the addition of weighting materials to prevent blow-outs.[26]

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[25] Pollard, J. A., and Heggem, A. G., *Mud-Laden Fluid Applied to Well Drilling,* Tech. Paper 66, Bureau of Mines, 1914, 21 pp.

Pollard, J. A., and Heggem, A. G., *Drilling Wells in Oklahoma by the Mud-Laden-Fluid Method,* Tech. Paper 68, Bureau of Mines, 1914, 27 pp.

Lewis, J. O., and McMurray, W. F., *The Use of Mud-Laden Fluid in Oil and Gas Wells,* Bull. 134, Bureau of Mines, 1916, 86 pp.

In most wells being drilled to great depth, especially where there is likelihood of the formations "heaving" or sloughing into the bore hole, chemical engineers (called mud engineers in the field) are constantly on hand studying the conditions of the well and carefully controlling the properties of the drilling fluid by the addition of chemicals or by other treatment. Some drilling fluids today contain very little water because water seems to aggravate the tendency of the walls of the hole to move into the well bore.[27]

A relatively new development is the addition of pulverized limestone to drilling fluids so that the mud sheath opposite the productive formations subsequently can be removed with acid.[28] Also, small particles of rubber have been suggested as an admixture. The rubber in the mud sheath may be dissolved by oil if present in the formations.[29] Thus, means are provided for extracting oil from horizons that may have been undeveloped intentionally or missed inadvertently during initial drilling.

Large quantities of other materials are placed in wells. The most important item in this category is cement which holds the casing in place and, if properly introduced into a well, prevents migration of fluids and damage to oil and gas zones by underground waters. The early technique of shutting off water from extraneous formations was to land the casing in a tapered hole, or "seat" drilled in shale (if such an impervious formation could be found) above the producing zone. The hope of the operators was that this "formation shut-off" would keep oil, gas, and water in their respective horizons. Some operators put bags of seed in their wells. When the seeds became wet, they swelled and acted as an imperfect packer. Both the seed bag and formation shut-off were expedients of the period of their use and led to many well failures. In 1918, Tough [30] discussed the state of knowledge then existing regarding the use of cement in shutting off water, and expressed the view that the topic "will doubtless be under consideration and discussion so long as there are enough known deposits of oil and gas remaining in the earth to make their development profitable." The fundamentals of excluding water from wells and cementing casing are the same now as they were when that statement was written, but many advances have been made, and new methods of introducing cement behind casings have been evolved to supplement or supersede the bailer, tubing, and "two-plug" methods described by Tough.

In the older cementing processes it was necessary to allow the well to stand idle for 14 to 21 days after placing the slurry or cement mix in order to permit the cement to set and harden. Then it was found that by adding certain chemicals the time of initial set was accelerated without weakening the structure of the hardened material. With deeper drilling, high earth temperatures caused cements to set too quickly, and ice water was used in some wells to reduce the temperature, making it possible to cement long strings of casing. Today the cement industry is able to supply a wide variety of cements that will meet almost any conditions in the natural reservoir.

New methods of introducing cement into wells also have been perfected. Multiple-stage cementing is a process by which a well may be cemented in steps, part of the material being introduced behind the casing through perforations. In this way it is unnecessary for all of the cement to be pumped to the bottom of the well and travel upward in the annular space between the string of pipe to be cemented and the wall of the hole or other casing of larger size that previously has been placed in the well. "Squeeze" cementing is another technique in which the cement is forced through perforations under high pressure into or against a permeable formation to shut off water or reduce gas-oil ratios. By the use of suitable packers, "floating-in" plugs that aid in running long strings of casing, cement guide shoes, and other requisite equipment the cement is placed at any desired depth in the well.

In some unconsolidated caving formations the practice of gravel packing has been found beneficial in preventing sand from accompanying the oil and clogging the perforated pipe opposite the producing sand in the well at the bottom of the hole. At first glance it may seem incongruous to remove rock material and then fill the space with a similar substance, but gravel properly introduced and placed acts as a filter, keeping back the fine-grained particles but allowing the liquid to flow through the channels into the wells.

Still other materials are introduced into wells, and chemical service companies constitute an important item in the present technique of oil-field practices. The acid treatment of wells may be considered as a method of stimulating production or it may be classed as a part of drilling technique, just as shooting a well with nitroglycerin may be considered a part of drilling.

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[26] Carpenter, Charles B., *Some Causes of Blow-Outs During Drilling and Means of Prevention, With Special Reference to the Gulf Coast Region*, Inf. Circ. 6938, Bureau of Mines, 1937, 27 pp.

[27] Sullins, C. A., and Van Dyke, Orien, "Methods that Drilled Heaving Shale to 13,728 feet in Agua Dulce Field," *Oil Weekly*, January 23, 1939, pp. 52–54 ; 56–57 ; 60.

[28] Miller, H. C., and Shea, G. B., *Chemical Method for Removing Mud Sheaths in Oil Wells,* Report of Investigations 3249, Bureau of Mines, 1934, 19 pp.

[29] Bowie, C. P., *Hardening of Mud Sheaths in Contact with Oil, and a Suggested Method for Minimizing Their Sealing Effect in Oil Wells,* Report of Investigations 3354, Bureau of Mines, 1938, 25 pp

[30] Tough, F. B., *Methods of Shutting Off Water in Oil and Gas Wells,* Bull. 163, Bureau of Mines, 1918, 122 pp.

The use of acid in wells dates back to the early patents of Frasch,[31] but the practical applications have been extended widely. The purpose of introducing acid into a well is to disintegrate the rock surrounding the well bore and to open new drainage channels through which oil and gas will flow toward the well. Thus the action of the acid increases the rate at which oil can flow into the well under the influence of a given difference in pressure. Many persons have a mistaken idea of the treatment of wells with acid and believe that the introduction of an acid into a well is all that is required to obtain oil production or an increase in the rate of flow. If the oil is not contained in the rocks, acid treatment will not be beneficial, and in some wells an increase in water or an occasional decrease in oil production is the result. The use of this method of stimulation has been confined to regions where the rocks in the reservoir are composed of limestone, chalk rock, or dolomitic materials, and the acid used is hydrochloric (commercial muriatic) acid. An inhibitor sometimes is added to the acid to reduce corrosion of the metal equipment in the well.

To all physical appearances a similar operation may be performed but with the view of obtaining the opposite effect; namely, the sealing of the earth strata to prevent the migration or infiltration of fluids. The "formation plug," applied recently on a commercial scale, is a development in the chemical treatment of wells in which the material is forced into a water-bearing formation, and because of chemical reactions a solid plugging material is formed.[32] Some operators believe that under certain conditions a formation plug may be used to equal or better advantage than cement.

The shooting of wells is almost as old as the industry, and the nitroglycerin or "soup" wagon drawn by horses with the cans of explosive cushioned in separate compartments was a familiar sight in fields drilled by cable tools where the formations were consolidated and the texture of the rock was designated as "tight." Although explosives are not used as extensively as they were in the past, there is a definite place for this technique to enlarge the diameters of bore holes drilled in hard formations, cutting off strings of pipe in wells, sidetracking tools or other material lost in wells, bringing in new production from close-grained formations, and stimulating production from partly depleted sands. The use of time bombs to detonate the charge[33] and sand tamping[34] instead of water tamping are two improvements in this type of service that are radical departures from the methods used by the "moonlighters"—the men who shot wells at night to circumvent the Roberts patents, applied for in 1864.[35]

No quantitative figures pertaining to the industry as a whole are available to show the volume of material introduced into wells, but when it is realized that a well frequently requires several thousand sacks of cement for one string of pipe,[36] that 5,000 or more gallons of acid or other chemicals may be injected into a well during a single treatment, that 1,000 quarts of nitroglycerin have been detonated in a well for a single shot, and that the supplying of admixtures and chemicals for treatment of drilling fluids has almost reached the proportions of a special industry, the scope of these service operations can be appreciated.

The drilling of vertical holes was brought to the attention of the industry forcibly during the development of the Seminole, Okla., field. Investigation showed that other fields also were being developed with "crooked" holes. Because of the desire to reach the producing horizons quickly, high drilling speeds were maintained. This condition combined with others caused holes to deviate so far from the vertical that some wells were ruined, and in others subsequent pumping became a major production problem. The first surveys were made by means of acid bottles in which a small quantity of hydrofloric acid was placed in a glass container and lowered at intervals into a well. The acid would etch a line on the bottle when the devise was brought to rest. By measuring the angles of deflection obtained with the acid bottle, a close approximation of the deviation of the hole was obtained.

Today the surveying of wells is a precise science requiring special surveying instruments. Not only is it possible to keep holes straight, but where conditions warrant, the bottom of a well may be drilled to a predetermined point several hundred feet laterally from the derrick floor. Controlled directional drilling has definite applications as in swampy regions and in permissible off-shore drilling. Carefully surveyed deflected holes are an essential part of drilling relief wells to intercept one that may be out of control. As an example of what can be accomplished in straight-hole drilling, the deepest well in the world was only 21 feet off center from the casing-head at a depth of 11,500 feet and from there to the bottom of this 15,004-foot hole the survey showed no inclination from the vertical greater than 2½°.[37] Such accuracy would be impossible without the control of drilling operations by means of gages that indicate the weight of the drill stem on the bit, the load on the derrick, the pressure of the mud pumps, the torque of the drill stem, and the speed of the rotary table.

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[31] United States Patent No. 556,669, granted to Herman Frasch on March 17, 1896.

[32] United States Patent No. 1,421,706, granted to Ronald Van Auken Mills on July 4, 1922, and dedicated to the public.

[33] Rison, C. O., "Manufacture of Nitroglycerin and Use of High Explosives in Oil and Gas Wells," *Trans. Am. Inst. Min. and Met. Engrs. Pet. Develop. and Tech., 1928–29*, pp. 240–312.

[34] Lewis, Paul F., "Oil-Field Explosives—Their Characteristics and Use," *Drilling and Production Practices, 1934*, Am. Pet. Inst., pp. 73–88.

[35] Smiley, T. F., "Shooter's Life Loses Old-Time Thrills," *Oil and Gas Jour.*, February 16, 1928, p. 31.

[36] See Bignell, L. G. E., "Oklahoma Well Takes More Than Two Million Pounds of Cement," *Oil and Gas Jour.*, August 18, 1938, pp. 46–47.

Better completion methods and equipment prevent impending blow-outs, and many wells are drilled and brought in under pressure control. In this method, oil or a mixture of oil and gas is used as the circulating fluid, and the flow from the well as the hole is deepened is controlled by special equipment. The method also has advantages in low-pressure areas, as the danger of forcing mud fluid or water into the formations is minimized.[38]

The connections and fittings on the derrick floor both during drilling and after completion of a well and the manifolding of high-pressure valves and fittings to meet any set of conditions is an engineering accomplishment that evokes admiration. These assemblies known as "Christmas trees" usually are made up and tested in the factory or pipe shop with the assurance that they are tight. The whole assembly is placed on the wellhead prior to completion, making it possible to "bring in" a well under control without spilling any oil or allowing gas to escape. This technique is quite in contrast with the old method of drilling a well to a producing horizon in the hope that it would flow over the derrick. If a "gusher" developed, methods then were devised to cap the well, and often vast quantities of oil and gas were lost, property was damaged, and lives were endangered. In the modern drilling technique the great valves and blow-out preventers stand guard at all times below the derrick floor, and at the newer rigs these may be closed with a power-driven mechanism upon an instant's notice at the first indication that the well may attempt to free itself from man's control.

Along with other evolutionary changes the power equipment at drilling rigs has been increased to meet the need. Oil-field boilers that operate at a steam pressure of 350 pounds per square inch may be seen at new rigs, sometimes in a battery of 3 or more. About 1884 gas engines for oil-field use were put on the market. Although gas engines are used more extensively in the production of oil than in drilling, some drillers prefer this type of internal-combustion engine, and units are now available that are connected with electric generators for use where power lines are not available. An exploratory well recently drilled in the Mid-continent area had a gas engine-electric generating unit that developed 1,200 horsepower. Diesel engines also are used either as a direct source of power or in generating electricity to operate motors at required places in the rig layout.

Testing formations by taking cores, making drill-stem tests, side-wall sampling, and electrical logging during exploratory drilling have been discussed in the previous section on exploration. This listing of improvements could be extended almost indefinitely, describing each piece of equipment from the cellar, stopping for detailed inspection of the enclosed draw works with its complicated gear-reduction mechanisms, to the crown block, but the items that have been mentioned should show clearly that wells no longer are drilled from the derrick floor alone and that vast quantities of costly materials must go into a hole before any oil or gas is taken out.

In 1930 engineers were surmising what would be required to drill to a depth of 15,000 feet.[39] That depth has been reached in one well, and the problem now resolves itself into means of reaching the basement rock regardless of depth at reasonable cost. The industry still has need for stronger and better steels, drill collars that will not twist off, and circulating fluids that will permit drilling through shales that heave and other formations under tremendous earth pressures and temperatures until the sedimentary rocks have been penetrated and the igneous rocks have been reached.

Production

This country has been accused of profligacy in its past production from its reserves of oil and gas and its present draft upon them. On the whole, however, the petroleum and natural-gas industries have improved their production practices through the constant application of technical knowledge, and this has been done without the continual goad of price influence.

Most early production practices were governed by opinion—sometimes haphazard—and by rule of thumb. There were no well-established ideas regarding the shape, constituents, and characteristics of petroleum reservoirs, and the composition and behavior of their contained fluids. Frequent reference was made to

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[37] Mills, Brad. "Setting Two New Depth Records," *Oil Weekly*, April 25, 1938, pp. 35–36.

[38] Ross, John S., "Review of Controlled Pressure Drilling Method," *Pet. Eng.*, vol. 7, No. 13, September 1936, pp. 116–121.

Winterburn, Read, "Pressure Drilling Operations at Kettleman Hills, and Effect on Initial Production Rates," *Trans. Am. Inst. Min. and Met. Engrs.*, vol. 127, pp. 39–47.

[39] Jeffery, W. H., "15,000 Foot Wells," *Nat. Pet. News*, November 12, 1930, p. 171.

"lakes and rivers of oil," and even at a much later period in fields having a natural-gas cap the gas was wasted to the air in the honest but mistaken belief that this was the only feasible way the oil could be made to travel through the formations to the wells.[40] A better understanding of accomplishment in the technique of producing oil is gained if it is kept in mind that a natural reservoir is a complex system obeying certain physical laws that control the relationships between the fluids contained in it and the energy available to bring these substances to the surface.[41]

Prior to 1920 experiments were performed by engineers of the Bureau of Mines[42] that for the first time gave visual demonstrations of certain tendencies of behavior of oil, gas, and water in natural reservoirs and established some tentative subsurface relations between the fluids and the surrounding rock material. Subsequent work has evolved a more complete understanding of these fundamentals based upon physical laws of fluid flow and energy. However, it was not until some years later that the industry began to appreciate the full significance of the function of gas in the production of oil.[43] Engineers of the industry now are giving the same studied attention to the function of water in the production of oil.[44]

Just as natural gas was unwanted in oil production some years ago, so water has been looked upon as a bane to the oil producer. If improperly controlled, water associated with oil in the producing horizons causes untold trouble, as has been indicated in the descriptions of methods to prevent its intrusion. However, the industry is coming to realize that in many fields if it were not for the energy available from the pressure of the water behind the oil in a reservoir system, recoveries would be much less and the cost of extraction would be greatly increased.

These and many other related reservoir problems have a direct bearing upon the spacing of wells. Recently the American Bar Association found that "probably between 4,000 and 5,000 unnecessary wells are drilled each year in the United States * * *." This problem of reducing the number of unnecessary wells is one of the most difficult conservation problems confronting the country because it is involved with many prejudicial opinions. Progress has been made, however, in sorting out and identifying engineering facts pertaining to the distance at which wells may be spaced and still obtain the recoverable oil. Some of the technical items upon which knowledge is being gathered relate to the way oil and gas are combined at high pressures and temperatures of the underground formations, how they flow through the porous rocks, the influence of water in the formations upon their production, and the way in which oil and gas separate as the fluids from a well are brought to surface temperatures and pressures.

One of the greatest aids to the extractive branch of the industry in establishing factual evidence of reservoir behavior has been the development of instruments that will record pressures and temperatures in wells and sampling devices that may be run into wells to obtain samples of oil-gas mixtures as they occur in their natural state. Hand in hand with the use of "bottom-hole" instruments are studies being made in engineering laboratories of the flow of oil, gas, and oil-gas mixtures through porous rocks. Methods for obtaining well cores have been discussed in the section on exploration. In the laboratory, the specimens are studied to find out characteristics such as porosity (a measure of the volume of the pore spaces or small holes in rock that may contain oil or other fluid), permeability (a measure of the time rate at which fluids will flow through porous rocks), and fluid content.

Although engineers had been studying temperatures and pressures at wellheads for some time and had applied these data in the operation of wells, it was not until about 1928 that published information on instruments for use in wells appeared in the technical press of this country.[45]

About this same time engineers of the Bureau of Mines began developing instruments to obtain subsurface data needed in the study of reservoir performance.[46] Today no progressive company would attempt to produce its wells without the aid of data obtained with recording and sampling instruments that are lowered into wells. In many fields operating groups voluntarily make periodic surveys of the pressures in "key" wells, and some State conservation agencies require these surveys. From subsurface temperature and pressure data engineers are able to determine efficient rates of withdrawal of oil and gas from the reservoir, and laboratory analyses of samples of reservoir fluid reveal characteristics of the fluid and suggest how it should be handled. For example, it is of primary concern to know whether the hydrocarbon fluid in the reservoir occurs as a gas or as a liquid and what changes may take place in the phase relations of the reservoir fluid as pressure and temperature conditions change.

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[40] Ross, J. S., *Engineering Report on Cotton Valley Field, Webster Parish, La.*, Tech. Paper 501, Bureau of Mines, p. 1.

[41] A concise description of fluid-energy relations in simple aspect is contained in a chapter from Bureau of Mines *Minerals Yearbook, 1934*, "Fluid-Energy Relations in Production of Petroleum and Natural Gas," by Cattell, R. A., and Fowler, H. C., pp. 710–711.

[42] Mills, R. Van A., "Experimental Studies of Subsurface Relationships in Oil and Gas Fields," *Econ. Geol.*, vol. 15, 1920, pp. 381-421; "Relations of Texture and Bedding to the Movements of Oil and Water Through Sands," *Econ. Geol.*, vol. 16, 1921, pp. 124-141.

[43] Miller, H. C., *Function of Natural Gas in the Production of Oil*, Monograph 4, Bureau of Mines, in cooperation with Am. Pet. Inst., 1929, 267 pp.

[44] American Petroleum Institute Research Project No. 27, Function of Water in the Production of Oil from Reservoirs, being conducted at the University of Michigan by Prof. F. E. Bartell and associates.

Miller, F. G., and Miller, H. C., *Résumé of Problems Relating to Edgewater Encroachment in Oil Sands*, Report of Investigations 3392, Bureau of Mines, 1938, 18 pp.

[45] Sclater, K. C., and Stephenson, B. R., "Measurements of Original Pressure, Temperature, and Gas-Oil Ratios in Oil Sands," *Trans. Amer. Inst. Min. and Met. Engrs., Pet. Develop. and Tech., 1928–29*, pp. 119–136.

[46] Reistle, C. E., Jr., and Hayes, E. P., *A Study of Subsurface Pressures and Temperatures in Flowing Wells in the East Texas Field and the Application of these Data to Reservoir and Vertical Flow Problems*, Report of Investigations 3211, Bureau of Mines, 1933, 17 pp.

Lindsly, Ben E., *A Study of "Bottom-Hole" Samples of East Texas Crude Oil*, Report of Investigations 3212, Bureau of Mines, 1933, 22 pp.

Berwald, W. B., Buss, H. A., and Reistle, C. E., Jr., *Bureau of Mines Multiple-Diaphragm Recording Subsurface Pressure Gage*, Report of Investigations 3291, Bureau of Mines 1935, 10 pp., 16 figs.

Another item of great importance is the shrinkage in petroleum that takes place not only because of changes in temperature in moving from the reservoir to the surface but also upon the liberation of gas from solution as the pressure is reduced. Some reservoir fluids shrink in volume more than 20 percent in reaching atmospheric temperatures and pressures. This condition has a very definite effect upon estimating reserves of oil in place.

The whole situation regarding the production of oil and gas has become more complicated in recent years with the advent of curtailed production and the drilling to deeper horizons where high temperatures and pressures exist in the reservoir. Many wells drilled to these deep zones produce large quantities of gas accompanied by relatively small quantities of liquid that has properties similar in some respects to gasoline and kerosene. These wells frequently are referred to as "distillate" or "condensate" wells. In preventing the wasteful use of natural energy and the loss of gas and oil, a more complete understanding of "combination" wells is necessary.[47]

Engineers now are giving studied attention to the phenomenon of retrograde condensation. In common ranges of pressure and temperature, liquids are condensed from natural gases upon suitable increase of pressure or lowering of temperature, but within the retrograde ranges of pressure and temperature, liquid formation may result from decrease of pressure or increase of temperature. Although this physical behavior has been known and studied from a scientific standpoint for many years in connection with phase relations of mixtures, it was not until about 1933 that Lacey and associates[48] brought this subject to the definite attention of petroleum engineers, and even now the complete applicability to production practices is not known. The reason this behavior is so important in oil and gas production is that unless wells producing in the so-called retrograde ranges of pressure and temperature are operated correctly, liquid hydrocarbons will be separated from the gas in the rock formations with attending loss of valuable products.

Although much is yet to be learned about production methods as applied to deep-seated horizons, some operators are taking advantage of the phenomenon of retrograde condensation and recovering greater quantities of hydrocarbon fluid from the reservoir than would be possible if the pressure were allowed to be reduced and liquid trapped in the pore spaces.[49]

To the end of recovering as much fluid as possible from reservoirs under flowing conditions of operation and reducing mechanical-lifting costs, trends in production technique are in the direction of maintaining the pressure in the producing sands at or near the original pressure. This is in direct contrast with the wide-open methods of production that were prevalent during earlier periods. Any reduction in pressure within the reservoir causes a decrease in the energy available for moving and lifting the fluid. The technical details of operation and the mechanical equipment necessary to run a pressure-maintenance plant are complicated,[50] but the principle is not new.

In substance, oil and gas are produced under controlled conditions, the liquid constituents are separated from the gas in high-pressure equipment, and the processed gas is compressed and returned to the producing horizon through carefully selected input wells at a pressure slightly greater than the pressure in the reservoir. Theoretically, this recycling process should bring virtually all of the liquid hydrocarbons to the surface, and in the end a reservoir of gas should remain to be drawn upon for use as fuel. The processes of pressure maintenance in many respects differ from those of repressuring sands as a stimulative method of secondary recovery, referred to in subsequent paragraphs.

In older fields where much of the natural energy of the reservoir has been expended or transformed without doing useful work, stimulative methods are employed. These secondary-recovery methods sometimes are referred to as "harvesting a second crop of oil." This designation is incorrect because so far as known there is no recurring generation of petroleum in commercial quantities of which man may be sensible. Actually, in this technique energy is supplied to the formations from external sources that will cause additional oil to flow to the wells whence it may be lifted to the surface. The best known methods of stimulative recovery are water flooding and gas injection. Where gas is not available, air sometimes is used. Lewis[51] has described both of these methods in detail, and the technical literature contains many references to these subjects.

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[47] Eilerts, C. K., and Schellhardt, M. A., *Flow Characteristics, Composition, and Some Liquid-Phase Properties of Hydrocarbon Fluids from a "Combination" Well*, Rept. of Investigations 3402, Bureau of Mines, 1938, 34 pp.

[48] Sage, B. H., Lacey, W. N., and Schaafsma, J. G., *Behavior of Hydrocarbon Mixtures Illustrated by a Simple Case*, Prod. Bull. 212, Am. Pet. Inst., 1933, pp. 119–128.

[49] Foran, E. V., "Development and Production Problems of High-Pressure Distillate Pools," Tech. Pub. No. 1023, *Petroleum Technology*, Am. Inst. Min. and Met. Engrs., February 1939, pp. 1–9.

[50] Bennett, E. O., "Pressure Maintenance"; Before Am. Pet. Inst. Mid-Year Meeting, May 1938, *Oil and Gas Jour.*, June 2, 1938, pp. 48, 50, 53, 55–56, 62.

The flooding of sands with water was confined for many years to the Bradford, Pa., field and to adjacent parts of New York State. Recently, however, other States, particularly in the midcontinent, have approved water-flooding projects. The principles back of introducing water into special intake wells and causing oil to be forced through the sands to recovery wells (by reason of the hydrostatic pressure, augmented by pressure applied with pumps) have been understood for many years. The earliest water drives that came to the attention of operators were accidental ones caused by leaky casing. Developments that have made the process far more applicable than formerly are: (1) The spacing of wells in definite patterns, such as the "5-spot"[52] and (2) the treatment of flood waters. The water may be filtered or treated with chemicals, or both, in order that the sand body subjected to a flood will not be plugged by the deposition of solid materials. It is reported that in northeastern Oklahoma from 40 to 60 percent of the remaining oil in the ground is being extracted by flooding methods, and in the Appalachian fields water flooding has added approximately 600 million barrels that never would have been recovered by ordinary methods of production.[53]

Recent progress in the use of gas or air as a repressuring medium has been in the direction of improvement in mechanical devices that permit injection of the gas under properly controlled conditions. Better advantage is being taken of possibilities of extracting gasoline from the gas returning to the surface, and with more information available on the characteristics of flow through sands, the injected gas is being introduced at selected points in wells where it will be more effective in driving oil to producing wells.

Unfortunately, many operators who have used these stimulative methods of recovery have done so with insufficient and incorrect advice regarding their application. When the method fails in their expectation, the whole technique is condemned. Actually, one of the greatest needs now confronting the industry is adequate education in the application of the knowledge that is available on the subjects of secondary recovery and storage of gas in partly depleted fields.[54]

When natural flow from wells ceases, the liquid must be raised by mechanical methods. The first wells were pumped from the walking beam, and the steam driven drilling engine was used to supply power for pumping. Some of this early-day pumping equipment may still be found in operation, but in general the industry has changed to single-well pumping units that are designed and counterbalanced to obtain maximum mechanical efficiency; or again, as many as 40 wells may be pumped at the same time from a central power by means of a suitable combination of eccentrics, pull rods, and direction-changing mechanisms. There are two types of these powers, the bandwheel type and the worm-geared power. In many fields electric motors are used because of certain advantages of efficiency, convenience, and smooth operation, but virtually all types of internal combustion engines are used in lifting oil to the surface.

Engineers have made detailed studies of rod loads with specially designed and constructed dynomometers to reduce rod breakage and pump troubles and to help in selecting and operating power units with particular reference to well conditions. One item of pumping technique that has been found helpful in some fields is the lifting of oil from one or more wells in addition to the one where the pumping unit is set. This is done by means of rods actuated by a "back side" crank attached to the prime mover.[55]

The inventions of well and well-head equipment that now aid in extracting oil by flowing or pumping methods are almost myriad. This fact is attested by many oil-trade catalogs, some of which have the attributes of technical treatises. As in the drilling department, producers of oil could not be supplied with material and devices of high tensile strength and proficient mechanical design without the aid of metallurgy.

The Oklahoma City field was a proving ground for a number of these devices because of the difficult pumping conditions peculiar to that field after natural flow ceased. The following items of pumping equipment have been described in considerable detail:[56] Single-crank bandwheel and twin-crank unit; submersible, electrical, centrifugal pumps; bottom-hole flow devices; intermitters; stage-lift pumps; pneumatic pumps; pump-head units consisting of a single-acting power cylinder; hydraulic pumping equipment; and bottom-hole pumps actuated by gas. These items, although giving no indication of the principles involved in the operation of the several mechanisms, suggest the wide scope of development in pumping equipment with a view of lifting oil more efficiently.

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[51] Lewis, J. O., *Methods for Increasing the Recovery from Oil Sands*, Bull. 148, Bureau of Mines, 1917, 128 pp.

[52] Simmons, A. C., "Recent Developments in Water Flooding," *Oil Weekly*, April 25, 1938, pp. 19–26.

[53] Miller, H. C., and Lindsly, Ben E., "A Report on Petroleum Development and Production," *Hearings Before a Subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, on H. Res. 441, Petroleum Investigation, 1934*, pt. 2 p. 1210.

[54] Schellhardt, M. A., and Rawlins, E. L., *Comparison of Output and Intake Characteristics of Natural Gas Wells in Texas Panhandle Field* Report of Investigations 3303, Bureau of Mines, 1936, 25 pp.

[55] For details of various pumping and lifting practices see *Oil and Gas Jour.*, Production Issue, February 24, 1938.

[56] Hill, H. B., Rawlins, E. L., and Bopp, C. R., *Engineering Report on Oklahoma City Oil Field, Oklahoma*, Report of Investigations 3330, Bureau of Mines, 1937, pp. 116–132.

One method of oil production that has not been mentioned is the gas lift. Historically, this method dates back to the first years of the industry.[57] In its simplest form, the process consists of injecting compressed air or gas into a pipe closed at the top, in which liquid stands at a given level, and in which a tube extends from a point above the top of the closed pipe to a level below the surface of the liquid. The injected gas depresses the liquid level in the pipe and causes it to rise in the eductor tube until some gas enters the tube. When the column of liquid in the eductor tube becomes aerated and more gas enters the bottom of the tube, the lightened column of gas-liquid mixture will flow out of the top of the eductor tube. As shown by Miller, the commercial applications in the field are complex.

Recent improvements in gas-lift operation have been mainly in the development of auxiliary equipment, making it possible to start flow at the necessarily high pressure and automatically changing to a lower operating pressure. Intermitters have been devised so that gas will flow into the well and lift the oil at predetermined intervals. Stage lifting with gas has increased mechanical efficiency and decreased power costs.[58] Shaw [59] has pointed out that the gas-lift method of producing oil has been regarded for many years as being adapted primarily for quantity production. Because of improvements in design of equipment and methods of operation, producers now may use the method advantageously and with profit in lifting small quantities of liquid.

Several attempts have been made in this country to apply mining methods to shallow sands that have lost their original gas pressure and have been partly drained of their oil content by other types of production operations. In parts of France and Germany definite technique to meet the conditions has been developed. These operations have been described in detail by Rice.[60] Only one or two "oil mines" are active in the United States. The latest operation in Ohio has had such a short history that information based on actual experience is meagre. Miller and Lindsly [61] point out general methods of recovering oil by mining. These may be summarized as follows:

1. Excavate and convey the oil-bearing sandstone to the surface for washing with water and chemicals to remove oil and return the washed and dried sand through bore holes to the excavated workings. This method is used in working one sand near Wietze in the Province of Hanover, Germany.

2. Drive entries in the cap rock to include a part of the top of the oil-bearing stratum. Sink sumps at intervals in the oil-bearing formation into which the oil will drain from the sand by gravity, whence it may be pumped to the surface with suitable equipment. This method also is used at Wietze.

3. Drive galleries in an impervious stratum above the oil-bearing formation and sink pits completely through the oil sand into a lower impervious stratum. Collect the oil from sumps and pump it to the surface as in item 2. This method is used at Pechelbronn, Alsace, France.

4. Sink shafts and bore wells into the oil sand, as in the so-called Ranney method [62] of which there are several variations.

In one type of operation a small shaft may be sunk to an impervious stratum below the oil sand and a system of tunnels and cross cuts may be driven from the bottom of the shaft. Care must be taken that no oil, gas, or water leak into the shaft. Small diameter wells with casings tightly sealed to the impervious rock are driven upward from the cross cuts into the oil horizon. Gas is forced into the oil sand under pressure through the wells of one cross cut (pressure tunnel). The purpose is to stimulate flow along a straight front to the wells of an adjacent cross cut (producing tunnel) from which oil is extracted. A modification is to sink a shaft to a desired level, and from its bottom to drill holes into the producing sand for a distance of 1,000 feet or more. These small diameter holes may be horizontal or their direction may be turned upward or downward as desired. It is claimed that this modification will reduce the cost of oil mining.

Rice [53] has pointed out the limitations in mining for petroleum. He refers to the unsuitability of mining to areas that have high pressures of gas, oil, or water in the sand, and suggests a possible limiting depth of 4,000 feet. Costs seem to be the controlling factor, and although oil mining has certain applications, the present restricted scope of its use in this country indicates that the petroleum industry is not ready to apply the method widely.

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[57] Miller, H. C., *Gas-Lift Method of Flowing Wells (California Practice)*, Bull. 323, Bureau of Mines, 1930, pp. 2–5.

[58] Hill, H. B., Rawlins, E. L., and Bopp, C. R., work cited.

[59] Shaw, S. F., "Advancements in Gas-Lift Operations," *Oil Weekly*, June 21, 1937, pp. 19–22.

[60] Rice, George S., *Mining Petroleum by Underground Methods*, Bull. 351, Bureau of Mines, 1932, 159 pp.

[61] Miller, H. C., and Lindsly, Ben E., work cited, pp. 1210–1214.

[62] Ranney, Leo, "Oil Mining for the Pennsylvania Fields," *Proc. Engr's. Soc. Western Pa.*, vol. 47, no. 6, June 1931, p. 315 and following.

[63] Rice, Geo. S., work cited, p. 3.

Certain methods that depend upon thermal reactions, such as injecting live steam and heated gases under high pressure into the sands, have been tried on an experimental basis.

Some time during the declining life of virtually every oil field the problem of brine disposal becomes an important factor. Although brine disposal is not a production method, as such, it is closely related to the extraction of oil and gas and in some fields is a controlling factor in economic operation. In fields close to the ocean oil producers have organized cooperative, nonprofit, brine-disposal companies that collect and pipe the brine to points where no harm will result from its disposal. Conditions in fields that are inland make the problem more difficult. However, most operators endeavor to avoid dumping brines where they will injure supplies of potable water, cause excessive mineralization of surface streams, destroy marine animal life, or interfere with agricultural and recreational pursuits. Scientific studies have shown that in many fields brines can be injected into suitable porous horizons and other petroleum wastes can be disposed of without harmful effects.[64] In underground disposal one of the most important advances is in treating water before injection so that precipitates or other solid materials will not plug the formations.[65] In this respect the problem is closely related to the stimulative method of water flooding, and on some properties the two objectives are served by the same treating plants and injection wells.

Water affects the economic production of oil in many harmful ways if not handled properly. One effect of water that has cost the industry millions of dollars is the formation of emulsions consisting of droplets of one liquid suspended in another.[66] When water is produced with oil, mechanical agitation is likely to disperse small droplets of the water throughout the entire body of the oil. Such a mixture is called "cut oil," and a water-in-oil emulsion is referred to commonly as "B. S. and W." Oils in this condition or with water suspended in them are not merchantable, and the emulsions must be "broken" with subsequent separation of the oil and water. Principal methods of breaking emulsions are: (1) Application of heat followed by settling; (2) addition of chemicals followed by settling; and (3) electrical dehydration. Centrifuges also have been used to separate water from oil.

In recent years much has been done to prevent the formation of emulsions. Attention is being given to the repair of wells that produce water, design of pumps—both in the wells and at the surface, straightening of flow lines and connections to reduce turbulent flow; and to removing conditions that cause gas to jet into mixtures of oil and water. Advances in practice that have resulted from technical research on the emulsion problem during the last 13 years are discussed in detail by Shea.[67]

The significance of newly found engineering facts and resulting changes in production technology (a few of which have been discussed in this section) can not be bounded by definite calendar limits. As in virtually all research, several years may be required to bring new ideas to a state of satisfactory practical application. However, there appears to be a definite trend toward greater efficiency and higher extraction. Less than 10 years ago frequent reference was made to recoveries ranging from 10 to 20 percent of the oil originally contained in the reservoir. Available figures show that fields operated in accordance with present knowledge of fluid and energy relations in the reservoirs and employing up-to-date equipment will produce 40 to 45 percent of their original oil. Some fields still in their producing lives where pressure maintenance has been practiced and where the available energy in the reservoir has been used advantageously have had recoveries as high as 70 percent of the oil originally contained in the formations.[68]

Transportation and Storage

The insistent urge for market outlet of the oil produced along Oil Creek, Pa., and vicinity during the first years of the industry soon brought a change in modes of transportation. The teamsters who hauled the oil in wooden barrels—sometimes receiving $2.50 to $5.00 per barrel for hauls ranging from 8 to 20 miles—and the men who barged their barrelled cargoes to steamers waiting on the Allegheny River, opposed the inevitable change. The first rail transportation began in 1865, and during that same year the first successful oil pipe line was put in operation, culminating a period of experimentation that was not always encouraging. The first rail transportation of oil was in what were termed "rotary oil cars." This rolling stock was little more than a flat car upon which were fastened two tanks: sometimes built of iron but more often of wooden staves with iron hoops. The capacity of the cars ranged from 80 to 100 barrels. A definite change in design took place about 1868 when horizontal tanks of iron were built. These were fitted with domes that permitted the expansion of the vapors in the tank, and valves were provided that could be opened or closed only with a special type of wrench.[69]

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[64] Schmidt, Ludwig, and Wilhelm, C. J., *Disposal of Petroleum Wastes on Oil-Producing Properties*, Rept. of Investigations 3394, Bureau of Mines, 1938, 25 pp.

[65] Taylor, Sam S., Wilhelm, C. J., and Holliman, W. C., *Typical Oil-Field Brine-Conditioning Systems; Preparing Brine for Subsurface Injection*, Rept. of Investigations 3434, Bureau of Mines, in cooperation with Kansas State Board of Health, 1939, 71 pp.

[66] Dow, D. B., *Oil-Field Emulsions*, Bull. 250, Bureau of Mines, 1926, 112 pp.

[67] Shea, G. B., *Practices and Methods of Preventing and Treating Crude-Oil Emulsions*, Bulletin 417, Bureau of Mines, 1939.

[68] Petroleum and Natural Gas Division and the Petroleum Economics Division, United States Bureau of Mines, "Conservation of Petroleum and of Natural Gas," Sec. IV, Paper 12, *Third World Power Conference*, Washington, 1936, vol. VI, p. 771.

From that time improvements continued with the result that today tank cars are pressure vessels, properly riveted or welded, usually with bumped heads, mounted on substantial trucks, and meeting the requirements of service in accordance with rigid specifications of the Interstate Commerce Commission. Some containers now used in transporting highly volatile liquids or gases under pressure are composed of large steel cylinders manifolded with high-pressure connections and fittings. Items that have added to the safety and economy of rail transportation of petroleum and its products are positive-acting safety valves, dome covers that permit gaging and loading without loss of vapors, outlet valves with positive-type seats, insulation to maintain the contents of the tanks at relatively even temperatures and thereby reduce evaporation losses, alloys that increase the tensile strength and reduce corrosion by chemicals used in the petroleum industry, and better design and sturdier construction of the trucks and supporting structure of the tank. Today the major transport service of tank cars is in the shipment of refined products.

The pipe line successfully operated in 1865 was 2 inches in diameter, 5 miles long, and handled 30 or 40 barrels an hour, pumped in two stages.[70] Despite opposition, some times at the point of rifles, pipe lines spread rapidly because it soon became evident that there was no better way of transporting fluids—for the principle is fundamental. By 1879 oil was being pumped over the Allegheny Mountains, and some years later a line from the Pennsylvania fields to the Atlantic seaboard was completed. In order to reach the refinery it was necessary to lay a portion of the line under Newark Bay and Staten Island Sound. This effort, completed with difficulty, probably was the first submerged line laid in deep water.[71]

Natural gas was distributed by pipe line even before oil, as the first recorded use of natural gas in this country was in 1821 near Fredonia, N. Y. Several of the early lines were hollowed logs joined together with metal sleeves. It is reported that a natural-gas line, 2½ miles long, was laid in Marietta, Ohio, in 1857, and a 2-inch iron pipe conveyed natural gas to Titusville, Pa., in 1872, from a source 5 miles away.[72]

There are now about 110,000 miles of trunk and gathering lines for crude oil, about 6,000 miles of gasoline trunk lines, and 80,000 miles of main transmission and gathering lines for natural gas that form a network covering virtually all parts of the country.

The main details of construction are generally similar for oil and natural-gas pipe lines. Looking backward to an earlier period, it is recalled that the "tong gang," making up a screw joint to the rhythmic beat of a hammer on the coupling, was a colorful picture of coordinated man power. However, "pipe lining" of that period had its limitations, and even the introduction of special kinds of flanges, couplings, and bell and spigot joints to join lengths of pipe did not have the effect on pipe-line technique that was caused by the introduction of line-welding methods. This innovation began to be felt in long-distance transmission of natural gas about 1927. Previous to that time a natural-gas transmission line 250 miles in length was an outstanding engineering accomplishment.[73]

However, the technique of oxyacetylene welding had been developing in the construction of relatively short oil lines for several years. About 1928 electric welding in the field led to other improvements. Here, again, these advancements could not have been made without the aid of metallurgical research that permitted the rolling mills to supply longer lengths of larger diameter pipe made of high carbon steel of greater tensile strength. Seamless pipes now are rolled that have tensile strengths ranging from 64,000 to 80,000 pounds per square inch. New types of flame tips for torches used in oxyacetylene welding and welding rods suited to the requirements of either gas or electric welding have made it possible to increase speed and to improve the strength of joints.

Concurrently with better welding technique and an increase in the strength of materials used in building the lines came new types of mechanical equipment for hauling, ditching, stringing, laying, painting ("doping"), and back filling. Some of these machines are almost uncanny in their precision of movement. For reconditioning old lines one type strips the dirt cover from buried pipe without puncturing it. If the line has threaded connections, a machine is available to unscrew and screw the joints of pipe. Some types of cleaning machines for both old and new pipe propel themselves along the length of the pipe. They are equipped with scrapers and wire brushes to remove mill scale, rust, and dirt. Another machine applies a smooth coat of hot "dope" of any desired thickness and immediately wraps the pipe with a tight spiral protective covering of paper, which may be impregnated, or other fibrous material to protect against corrosion.

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[69] For a more detailed account of the development of tank cars, see *Oil and Gas Jour.*, Diamond Jubilee Number, August 23, 1934, p. 23.

[70] Sneddon, R., Kiessling, R. L., Ross, J. S., Hopkins, G. R., "Advances in Transportation and Storage Techniques," *Mineral Technology, Employment, and Output per Man in Petroleum and Natural-Gas Production*, ch. IX. Works Progress Administration, National Research Project in cooperation with the Bureau of Mines, 1939.

[71] *Oil and Gas Jour.*, Diamond Jubilee Number, August 23, 1934, pp. 55–57.

[72] *Oil and Gas Jour.*, Diamond Jubilee Number, August 23, 1934, p. 41.

[73] Federal Oil Conservation Board, *Report IV*, May 1928, 1930, p. 10.

Excavators of different types, back-filling machines, and trucks and tractors equipped with winches and booms are doing work more quickly and effectively than was possible with manual labor.

Maintenance problems begin almost as soon as a new line is completed. Some soils are especially destructive to pipe lines because of their corrosion-inducing characteristics, and stray electrical currents cause pitting in and subsequent leakage from lines if protective measures are not taken. Soil surveys, corrosion tests, and other studies made in field and laboratory have circumvented many of these difficulties. Research conducted by the National Bureau of Standards, in cooperation with the American Gas Association and the American Petroleum Institute, has contributed greatly to the efficacy of measures taken to extend the working lives of pipe lines.[74]

If a certain locality is found to be a "hot spot," as, for example, marshy ground where the soil is especially acid in its reactions, it may be economical to change the course of the proposed line. If this is not feasible, extra precautions may be taken in the way of protective coatings, or corrosion-resisting materials may be used in the manufacture of the pipe. The kinds of protective materials differ widely in specification and may be "dopes" of asphaltic material, various kinds of enamels, or fibrous materials, such as paper or felts. Frequently a combination of coatings is used. These may be applied either at the factory or in the field.

During the research being conducted by the National Bureau of Standards, a relation was found between electrical currents traveling in the pipe and soil and certain types of corrosion. To combat this condition, cathodic protection[75] was devised in which low-voltage currents are sent through lines. If the lines are properly energized, the electrolytic action is reduced. Electric generators propelled by wind power are used on many lines. Geophones and radio equipment have been developed to detect leaks.

In natural-gas transportation, leakage at one time was responsible for the loss of such large volumes of gas that between 1922 and 1928 the Natural Gas Association of America (now the Natural Gas Section of the American Gas Association) and the Bureau of Mines conducted fundamental research and field tests to determine quantities lost and means of prevention.[76] The results of this study have been instrumental in causing the leakage problem in long-distance transmission of natural gas to be reduced to one of minor importance. However, the repair of offending lines did not mean that the work was ended for the operating companies. The replacement of screwed lines with welded lines and the laying of new lines of better construction were large factors in reducing these losses, but as the age of any line increases, the likelihood of leakage becomes more acute, and periodic leakage surveys are a part of the operating procedure of every natural-gas transporting company.

Another operating problem of the natural-gas industry is the plugging and consequential interrupted service in main trunk lines supplying gas to market outlets. Substances known as gas hydrates that have the outward appearance of ice or icy slush sometimes form in lines that are operated under high pressures. These gas hydrates are combinations of water and hydrocarbons that begin to solidify at temperatures above 32° F., the temperature at which water freezes. Research in which the Bureau of Mines and the American Gas Association have cooperated has revealed much information regarding the deposition and characteristics of these substances and methods of preventing their formation. Means taken to cope with this condition are careful control of operating pressures in the lines, dehydration of the gas before it is pumped into the lines, and treatment of the gas with small quantities of ammonia and other substances.[77]

Oil will not flow nor gas travel of their own accord for any great distance through pipe lines. Therefore, the heart of the pipe-line system is the pump or compressor station. Many crude-oil pumps are of the reciprocating type and are massive in construction. Main-line crude-oil pump stations have been built with a total capacity for handling 198,000 barrels per day. An outstanding achievement in oil transportation was the development of equipment that would pump light products such as gasoline over long distances through large-diameter lines. Although gasoline was pumped a distance of 2 miles through a 2-inch line in California as early as 1912, about 14 years elapsed before trunk-line transportation of gasoline became an actuality. This was made possible by multiple-stage centrifugal pumps of which there are now several types. These may be driven by gas engines, Diesel engines, or electric motors. Compact single units of 700 horsepower capable of handling 38,000 barrels of gasoline in 24 hours are quite in contrast with older types of heavy pumps used in crude-oil transportation.

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[74] Ewing, Scott, *Soil Corrosion and Pipe Line Protection*, Amer. Gas Assoc., 1938, 277 pp.

Logan, Kirk H., "Recent Developments Related to Underground Corrosion," *Oil and Gas Jour.*, September 22, 1938, pp. 212, 214, 219

[75] See works of Ewing and Logan, footnote 74.

[76] Rawlins, E. L., and Wosk, L. D., *Leakage from High-Pressure Natural-Gas Transmission Lines*, Bull. 265, Bureau of Mines, 1928, 108 pp.

[77] Deaton, W. M., and Frost, E. M., "Gas Hydrates in Natural-Gas Pipe Lines," *Proceedings, Natural Gas Department, American Gas Association*, 1937, pp. 23–31. "Gas Hydrates," presented before 1938 annual meeting Natural Gas Department, American Gas Association. See *Gas Age*, May 26, 1938, pp. 33–34, and *Gas*, June 1938, pp. 31–32

Booster and main-line compressor stations on natural-gas lines serve the same relative purpose as pump stations on oil and gasoline lines. Some of the newer stations are the acme of mechanical perfection, capable of handling 60 to 70 million cubic feet of gas per 24 hours.

In both oil and natural-gas transportation, communication is an important factor. Oil is dispatched through pipe lines in much the same way that trains are sent out on schedule over a railroad system. Because of this precision in dispatching, crude oil, distillate, or gasoline that meets a certain specification, may be delivered to a refiner or marketer with an overlap, or mixing, that is only a few barrels when compared with the total shipment. Constant communication is an essential requirement in maintaining uninterrupted service in natural-gas distribution to meet changing load and weather conditions.

In 1930 working pressures of 350 or 400 pounds per square inch were commonly used in the long-distance natural-gas transmission lines then in operation. However, attention was directed to certain economies of smaller diameter pipe with greater wall thickness "under pressures as high as 1,500 pounds per square inch." [78] Although a majority of natural-gas lines still are being operated at pressures ranging from 300 to 400 pounds per square inch, several lines are operated at much higher working pressures, and 700 to 800 pounds per square inch is not uncommon. A 12-inch line extending from Charlteston, W. Va., to Pittsburgh, Pa., a distance of about 90 miles, has been built for ultimate operation at 1,500 pounds per square inch, although the present maximum operating pressure is 1,300 pounds per square inch.[79] The pressures for crude-oil pipe lines usually are less than those for natural gas, although some of the newer gasoline lines work at pressures of 800 to 900 pounds per square inch.

The diameters of the pipes handling oil also differ from those laid expressly to transport natural gas. Diameters of crude-oil trunk lines usually fall within the range of 8 to 14 inches, whereas natural-gas trunk lines may be 36 inches in diameter, although 12 to 18 inches are sizes more commonly used.

Much has been done in developing flow formulas for crude oil, gasoline, and natural gas. Liquid flow in pipes has been the subject of several published treatises, and the effect of power profiles on the placing of pump stations has been discussed.[80] Special studies have been made on natural-gas transmission resulting in the derivation of formulas suitable for computing the flow through high-pressure natural-gas transmission lines. It is now possible to design a new line or parallel an existing line to meet any specified requirements.[81] The overall effect of this continued attention to the technical phases of pipe-line construction and operation is more efficient flow of both oil and gas and the balancing of load factors that will assure more economic operation and the continuous delivery of these essential fluid minerals to ultimate consumers.

Aerial mapping, discussed under exploration, also has reduced the time and cost of making reconnaissance surveys of rights-of-way for new lines over broken ground and has revealed errors in previous land surveys.

Marine transportation of petroleum appeals to every person who finds romance in ships and the sea. On the practical side, the volume of cargo ranks second only to pipe-line shipments. Not only is oil carried to distant foreign ports, but petroleum and its products constitute a large tonnage in coastwise and inland-waterway traffic of the United States. Barging did not stop with the shipments on Oil Creek. Large barges with tight compartments fitted in their hulls carry oil, refined products, and asphaltic materials wherever the depth of water permits them to float. Cost is a large factor in the competition between water and pipe-line shipments in this country.

A sailing vessel, *The Charles*, was fitted with iron tanks and carried oil during the years 1869–72. Tank steamers began to appear about 1872. The modern tanker represents the best efforts of marine architects.[82]

Improvements in loading and unloading facilities have kept pace with increased speeds and larger capacities of ocean-going tankers. Welded plates have decreased corrosion of the hulls and aided in cleaning the interiors of the compartments. Greater efficiency has been developed in both steam turbine and turbo-electric types of propelling machinery. Diesel engines also are used and are especially adapted to shallow-draft tankers because of their light weight and compact dimensions, thus giving more space for oil cargo.

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[78] Federal Oil Conservation Board, *Report IV*, May 28, 1930, p. 13.

[79] *Gas Age*, January 19, 1939, p. 42.

[80] Danforth, R. S., *Oil Flow in Pipe Lines*, 2d ed., San Francisco, Calif., 1927. (Set of flow charts.)

Heltzel, Wm. G., "Fluid Flow and Friction in Pipe Lines, *Oil and Gas Jour.*, June 5, 1930, p. T–203 and following.

Bowie, C. P., *Transportation of Gasoline by Pipe Line*, Tech. Paper 517, Bureau of Mines, 1932, 24 pp.

Wolf, Oscar, "Economic Design of Oil Pipeline Transportation Systems": before first national meeting Petroleum Division, Am. Soc. Mech. Engrs., Tulsa, Okla., October 1930; published in *Petroleum Mechanical Engineering*, October 1930.

[81] Johnson, T. W., and Berwald, W. B., *Flow of Gas Through High-Pressure Transmission Lines*, Monograph 6, Bureau of Mines, in cooperation with the American Gas Association, 1935, 120 pp.

[82] Norman, H. Stanley, "Ocean Tankers, Inland Barges," *Oil and Gas Jour.*, September 22, 1938, pp.. 60–61.

At some terminals it is impossible for the tankers to dock at wharves because of shallow water. Under these conditions ingenious marine pipe lines have been laid to points off shore where the tankers can anchor. Some of these lines, over a mile in length, have been laid first on shore and then pulled out to the terminal point with tug boats. Automatic equipment at both the shore and water ends of the loading line are requisite to safe loading. If a break in the line or flexible connection to the tanker should occur, quick-closing valves immediately go into action, and spillage is almost negligible.

Storage tanks and containers of a wide variety of sizes, shapes, and strength are required from the time oil first reaches the surface of the ground until its products are consumed. The first tanks were of wood without tops. This construction caused great losses of petroleum vapors rich in gasoline. Although some wooden tanks equipped with vaportight roofs now are used in fields where the oil is produced with corrosive hydrogen sulphide gas and the oils have a high content of sulphur compounds, most of the material used in tank building is steel. At different periods throughout the history of the industry when tankage has not been available, oil has been stored in earthen pits with resulting loss from seepage and evaporation, but this wasteful practice is not generally current. Various types of riveted, bolted, and welded tanks are available from manufacturers. An outstanding exception is the concrete reservoir. Some companies, particularly in California, have found it advantageous to store large quantities of heavy crude oil (sometimes over 1 million barrels) in one storage container, most of which is below the surface of the ground. The reservoirs are protected against lightning with grounded networks of wire supported by steel towers.

To provide working stocks of petroleum, tank farms are built at strategic places near oil fields, along pipe lines, and at refineries.[83] Most of these large storage tanks hold 55,000 or 80,000 barrels of crude oil each. The building of these structures requires the solving of many difficult engineering problems. Tanks of smaller capacity usually are provided for the storage of refined products.

One of the greatest achievements in technical advancement is the reduction in evaporation losses from storage containers of all types.[84] Surveys made by the Bureau of Mines in the midcontinent area during 1920–24 showed that the over-all loss from the time the oil left the wells until it was processed through the refinery was about 8 percent of the volume of oil handled. A more recent survey indicates that improved methods and equipment have reduced this loss to less than 3 percent. Considering the quantities of oil handled, this reduction in loss is equivalent to a saving of millions of dollars.[85] This improvement has been brought about through various ways, but all efforts are directed toward vaportight tankage and minimizing losses caused by "breathing." This action is the alternate expulsion of vapors from a tank and the drawing in of air caused by changes in temperature. To reduce this effect tanks are painted light colors, cooled with water, or insulated with heat-resisting materials. Various types of roofs keep the vapor space of a tank at a minimum. Some roofs float on the surface of the liquid, and others, of the diaphragm type, move to correspond with the vapor conditions in the tank. Still other tanks are equipped with breather bags or flexible metal containers that permit movement of the expelled vapors without loss to the air.

Oils that are highly volatile are stored in tanks of spherical or spheroidal shape. This type of construction permits greater internal pressures without rupture than can be placed on cylindrical tanks. Vacuum and relief valves now are standard equipment on all well-constructed tanks. These valves hold a predetermined pressure within a tank and act as safety valves before hazardous pressures are reached.

Containers for stored products at service stations and for domestic uses are familiar sights, but many persons do not realize that engineering thought and careful testing are back of the safety and convenience of all this equipment that serves the individual in daily work, recreation, and home comforts. In like manner, throughout the whole transporting systems for petroleum and natural gas, engineering accomplishment has made possible the uninterrupted flow of hydrocarbon fluids from wells to manufacturing plants and consumers.

Refining

The refining branch of the petroleum industry transforms crude oil into usable products for which a demand exists. Refining processes have evolved gradually from a simple distillation of crude petroleum into one salable component (kerosene) to the point that refining processes now comprise a wide variety of chemical transformations and physical operations to produce many commercial products. This evolution of petroleum refining has brought about a notable improvement in petroleum conservation by increasing the proportion of most desired products and correspondingly reducing the volume of materials of lower commercial value.

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[83] *Survey of Crude Oil in Storage, 1936–1937,* Rept. of Investigations 3417, Bureau of Mines, prepared by Petroleum Economics Division and Petroleum and Natural Gas Division, 1938, Appendix 1, Crude Oil Tanks, pp. 35–42.

[84] Schmidt, Ludwig, *Applied Methods and Equipment for Reducing Evaporation Losses of Petroleum and Gasoline,* Bull. 379, Bureau of Mines, 1934 (reprinted 1937), 160 pp.

Schmidt, Ludwig, and Wilhelm, C. J., *Reduction of Evaporation Losses from Gasoline Bulk Storage Stations,* Tech. Paper 565, Bureau of Mines, 1935, 35 pp.

[85] Schmidt, Ludwig, *Hearings before a Subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives on H. Res. 441, Petroleum Investigation, 1934,* pt. 3, p. 1954.

The early refineries operated on the batch system. Stills were of two general types, horizontal cylinders and vertical cylinders with cone-shaped tops. The latter were known as "cheese box" stills. Both types of stills were supported on brick walls, enclosing a space in which fuel was burned to heat the still contents. As the oil vaporized, the vapors passed from the still into condensing pipes immersed in water. The distillate was drawn off into shallow open pans, where the lighter fractions were allowed to evaporate.

The weathering process, although extremely wasteful when measured by present-day standards, was suited to the demands of the time. Weathering, or forced evaporation of the lighter constituents, directly contrary to the modern efforts to save this portion of the crude oil, was necessary to produce a kerosene that was not too inflammable.

Continuous distillation was the first major improvement in refining technique.[86] Although a patent for this process was granted as early as 1860 and small beginnings were made about 1885, continuous operation in distilling oil was not applied on a large scale until the turn of the century. A battery of shell stills was connected in a series, which involved charging the first still with crude oil and distilling the lightest hydrocarbons from the charge. The residual oil from the first still passed through the other stills in the series; a distillate was taken from each still, and the final residuum was pumped from the last still. Higher temperatures were maintained in each successive still, and the stillman controlled the quantity and gravity of the distillate from each still by regulating the rate of flow of oil from still to still and the rate of firing each still. This system gave refiners the advantages of a much larger capacity, lower fuel and labor costs, and better control of the finished products.

The substitution of pipe stills for horizontal shell stills was an important development in the refining process. The tube or pipe still was first used in California primarily for dehydrating and stripping crude oils of low gasoline content.[87] The tubes through which the oil passed were inclosed in a furnace so the radiant as well as the convection heat from the fuel was utilized to heat the charge. The tubes first used were large in diameter but later were reduced in size so the oil could be moved more rapidly through the pipes to reduce the formation of deposits of coke, crystalline salt, and other foreign matter. A new type of connection for joining the ends of the pipes used in the still further facilitated cleaning by removal of plugs fitted to openings in these connections.

Early fractionating equipment consisted of baffles or similar separators installed in the vapor line between the stills and condensors, which caught the entrained liquid from the stills and prevented the heavier products from going through the condensors into the receiving tanks. This gave a better separation and an improvement in the products. Various types of aerial towers were built about the time continuous distillation came into use. In 1905 William Irish and John Van Dyke, using an air-cooled, stone-packed tower, first distilled crude oil to coke in a single step. The fractionating tower was introduced about the time of the development of the pipe still. In its early form this tower was a simple vertical column filled with stone, which broke up the flow of vapors traveling through the still and separated one fraction from another. About 1915 the towers consisted of cylindrical drums containing stones or equipped with baffles so arranged that portions of the distilling vapors would condense in certain sections of the tower and could be collected on ring trays. The towers were next improved by providing means for condensing part of the vapors inside the tower or by pumping liquid back into the tower from the side streams to increase the degree of fractionation.

Later, bubble towers were used, in which the ascending vapors were forced to pass through shallow layers of liquid trapped in horizontal trays within the tower. The liquid on each successively higher tray in the series was at a lower temperature and thus caused fractional condensation of the vapors. Distillate was removed continuously in side streams from selected trays. Previously the general practice had been to distill the crude oil in a number of steps, each of which involved a loss of product as well as increased cost of operation. The number of trays have a direct relationship to the degree of fractionation and the quality of the products. Experiments are still being conducted to determine the number of trays and other variable factors that will result in the most efficient fractionation.[88]

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[86] Bacon, R. F., and Hamor, W. A., *The American Petroleum Industry*, vol. 2, 1916, pp. 533–53.

[87] Wadsworth, J. M., *Removal of the Lighter Hydrocarbons from Petroleum by Continuous Distillation*, Bull. 162, Bureau of Mines, 1919, 162 pp.

Although from the start of petroleum refining, boiling temperatures were reduced by the use of steam, it was not until a much later period that high vacuum was used for the same purpose. Subsequently vacuum fractionating towers were developed which permit the evaporation and fractionation of relatively high boiling-point fractions without decomposition. Two-stage fractionating towers and pipe stills and their combination into a single unit represent one of the greatest advances in refining technology.

The cracking process was the most radical advancement in refining technique. By this process, which employs high temperatures usually with high pressures, petroleum fractions are altered chemically to the extent that the products cover the range from hydrogen gas to coke. The objective of the cracking process is to form as large a proportion as possible of products within the gasoline range of volatility from raw material that contains no materials in this range. An exception is re-forming, which is a cracking process that alters the chemical characteristics of compounds in straight-run gasoline to increase the octane rating. The yield of re-formed gasoline usually is approximately 15 to 25 percent less than the amount of straight-run gasoline or naphtha charged to the unit.

The first commercial cracking operations began about 1912, using an intermediate distillate (gas oil) in batch units. At present even heavy crude oils are cracked in large continuous cracking plants, the volatile products passing through bubble towers connected directly with the cracking unit. The bubble towers deliver a continuous stream of finished gasoline requiring no further fractionation.

The success of cracking operations depended largely on technical improvements in the equipment. Pipe stills in cracking plants improved fuel and reduced coke and gas formation. Alloy steels that withstand long exposures to high pressures and temperatures without breaking down, and which resist deterioration from corrosive charging stocks, were developed for tube manufacture. Whereas temperatures of 740° F. and pressures of 75 pounds per square inch were used in the early shell-still cracking operations, severe conditions employed today in cracking require temperatures ranging from about 900° F. to over 1,100° F. and pressures as high as 2,000 pounds per square inch. Improvements in furnace design have permitted closer control of the heat flow through the cracking-tube system, more uniform yield, lessening of coke deposition, and a longer trouble-free operating time, all of which results in a reduction in furnace maintenance and operation cost. By proper design and operation, over-all efficiencies as high as 80 percent based on the lower heating value of the fuel may be obtained from cracking furnaces.[89]

Mechanical firing, the greater use of heat exchangers (devices by which the heat from hot oil to be cooled is used to heat the incoming cold oil), and other improvements in refining equipment have accounted for improved fuel efficiency. These improvements include greater use of heat from hot gases to preheat air, use of exhaust steam formerly wasted, improved technique in generating and using steam, substitution of electric-driven for steam-driven equipment, and reduction of heat losses through better insulation. Furthermore, the cost of operation has been lowered through the wider adoption of automatic control devices[90]—combinations of recording instruments and regulation mechanisms which make possible the accurate control of temperature, pressure, rates of flow, and liquid levels. Automatic control devices provide not only more reliable coordination of the various processes, but also important savings in labor requirements. The life of refinery equipment has been prolonged by the introduction of measures for combating corrosion. Treatment of crude oil to remove foreign material such as salt[91] further lengthens the time a plant may be kept in operation without cleaning.

Due to these and many other technical improvements, there has been a decided reduction in the cost of fuel used at the refinery. During the 11-year period, 1926 to 1936, the energy consumed in refining a barrel of crude petroleum decreased from 847,900 B. t. u. to 643,400 B. t. u., a decrease of 24 percent. Savings in total fuel requirements have been accompanied by a change in the kind of fuels used, with a decided trend toward the use of refinery gases and other fuel by-products of refining, which until recently were allowed to go to waste. One of the most important factors in the reduction of unit energy requirements is the change from batch stills, which had a fuel efficiency of about 40 percent, to pipe stills with a fuel efficiency of 75 to 80 percent.

Along with the development of cracking equipment came improvements in treating processes. Essentially the same process used in the early days to treat kerosene is in common use today along with other processes. Sulfuric acid is still the major chemical used for treating petroleum fractions. Methods are in use for treating distillates with sulfuric acid at low temperatures that are more economical and cause less loss of valuable constituents of the distillates. Most of the cracked gasoline is water washed and treated with caustic soda or sodium plumbite, a solution of lead oxide (litharge) in aqueous caustic soda. Although sodium plumbite is still used extensively for treating sulfur compounds in gasoline and kerosene, other treating processes have been adopted recently. As the percentage of cracked gasolines increased, the problem of discoloration and gum disposition took on importance. The Gray Process,[92] whereby gasoline vapors are contacted with fuller's earth in towers improved the color and lowered the gum content of gasoline. Recently antioxidants[93] also have been used to inhibit gum formation in cracked gasoline.

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[88] See series of articles by Nelson, W. L., on fractionating complex mixtures in the following issues of the *Oil and Gas Journal;* July 21, 1938, p. 41; August 4, 1938, p. 44; August 18, 1938, p. 58; September 15, 1938, p. 46.

[89] Rickerman, J. H., Lobo, W. E., and Baker, A. L., "Fundamentals Involved in the Design of Cracking Furnaces," *Oil and Gas Jour.,* May 5, 1938, p. 50, and May 12, 1938, p. 141.

[90] Bergman, Donald L., "Application of Automatic Control in Oil Refining, *Oil and Gas Jour.,* December 16, 1937, p. 49.

Darling, P. E., "Measurement and Control in Refinery Processes," *Oil and Gas Jour.,* November 18, 1937, p. 67.

[91] Christianson, L. F., and Horne, Joseph W., *Desalting Crude Petroleum: A Review of the Literature,* Report of Investigations 3422, Bureau of Mines, 1938, 28 pp.

With increased compression ratios in automobile engines and the development of high-compression aircraft engines, greater emphasis was placed on the quality of gasoline and its tendency to detonate or "knock." A standard of measurement of the ability of fuels to resist detonation, expressed in terms of octane numbers, was proposed by Edgar[94] in 1926 and has been adopted widely.

A very important discovery by Midgley and Boyd[95] in 1922 enabled refiners to improve the knock characteristics of motor fuels by the addition of minute quantities of a hitherto obscure organic compound of lead, called tetraethyl lead. Today 75 percent or more of the gasoline sold contains this anti-knock agent.

Natural gasoline, extracted from natural gas, in which it exists in vapor form at normal atmospheric temperatures and pressure, comprised approximately 8.5 per cent of the volume of motor fuel produced in the United States in 1937.[96] Processes of extraction involve one or more of the following steps—compression of the natural gas as it comes from the well, refrigeration of the natural gas or the compressed gas, and absorption of the liquid constituents of the natural gas, either in a heavy oil or on charcoal. The absorbed liquids subsequently are driven from the absorbing medium by heat, and condensed to liquids again. Combinations of the methods may be used. A process recently placed in operation in a plant at Benavides, Texas, does not use absorption but employs rather a combination of refrigeration and a substantially complete dehydration of the gases. The process is said to show high recovery, and advantages of flexibility and simplicity of equipment and operation, as well as relatively low utility requirements.[97]

Through improvements in methods of manufacturing, the yield of natural gasoline per 1,000 cubic feet of gas processed continued to increase until 1929, when controlled stabilization for the removal of the highly volatile fractions (propane and butane) was developed extensively. The yield continued to decrease until 1935, when it started to increase again, reflecting, in part, improved equipment and in part the increased use of gas from east Texas, a high-yield area.[98] A large part of the volatile fractions, formerly lost by weathering, are utilized as liquefied petroleum gases.[99] An outlet for these volatile fractions that promises to increase in importance is the manufacture of high anti-knock gasoline by polymerization—a process which is the reverse of cracking in that gases and volatile liquids are synthesized to gasoline.

Some of the hydrocarbons remaining after natural gas and refinery gases have been stripped of their light hydrocarbons suitable for use as motor fuels may be cracked and dehydrogenated and finally polymerized to form nondetonating fuels. The polymerization process is a definite advance in chemical control of the composition and properties of motor fuels and thereby has enabled refiners to meet the increased demands of automobile and aircraft industries for high octane-number fuels. Iso-octane, the principal blending stock for aviation fuels, ranging from 95 to 100 in octane number, is produced from cracked gases that are polymerized and then hydrogenated. Although formerly only the iso-butylene content of gas was used, thus limiting the quantity available, normal butylene and dehydrogenated butanes contained in refinery and natural gases now are used to form the iso-octenes which are converted by hydrogenation to iso-octanes. Use of other blending stocks is possible since the development of the polymerization process.[1] Experiments show the savings resulting from the use of 100 octane aviation fuels,[2] and the progress in the preparation of such fuel is important not only from the standpoint of commercial aviation companies but also from the standpoint of national defense. Some gasoline with knock rating exceeding 100 octane has been manufactured, but at present the cost of producing such gasoline on a large scale is prohibitive.[3]

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[92] Nash, A. W., and Howes, D. A., *The Principles of Motor Fuel Preparation and Application*, vol. 1, 1935, John Wiley & Sons, Inc., New York.

[93] Dryer, C. G., Morrell, J. C., and Egloff, G., "Antioxidants as Stabilizers for Cracked Motor Fuels," *Oil and Gas Jour.*, March 25, 1937, p. 113.

[94] Edgar, Graham, "Measurement of Knock Characteristics of Gasoline in Terms of a Standard Fuel," *Ind. Eng. Chem.*, vol. 19, no. 1, January 1927, pp. 145–146.

[95] Midgley, Thos., Jr., and Boyd, T. A., "The Chemical Control of Gaseous Detonation with Particular Reference to the Internal-Combustion Engine," *Ind. Eng. Chem.*, vol. 14, no. 10, October 1922, pp. 894–98.

[96] White, A. G., Hopkins, G. R., Breakey, H. A., "Crude Petroleum and Petrolem Products," *Minerals Yearbook, 1938*, Bureau of Mines, p. 866.

[97] Wilson, D. W., "Dehydration and Refrigeration for Natural Gasoline Recovery," *Oil and Gas Jour.*, September 29, 1938, p. 48.

[98] *Mineral Resources, 1930*, pt. II, Bureau of Mines, pp. 435, 437. *Minerals Yearbook, 1937*, Bureau of Mines, p. 1104.

[99] Hopkins, G. R., "Natural Gasoline, Including Liquefied Petroleum Gases," *Minerals Yearbook, 1938*, Bureau of Mines, pp. 957–961.

[1] Hubner, W. H., and Egloff, Gustav, "Aircraft Fuels of High Octane Rating," *Oil and Gas Jour.*, March 31, 1938, p. 103.

Segregation of technically pure hydrocarbons is now possible due to the advancement in design of fractionating equipment heretofore not commercially available, and through separation of the so-called dry gases (ethane, propane, and butanes) refiners are better able to utilize them for polymerization. Because of these new processes used in petroleum refineries, petroleum has increased in importance as a raw material for the manufacture of chemical products.[4]

Although hydrogenation plants now are operated for special products, present economic conditions prevent a wide commercial adoption of this process. In 1931 it was estimated that the hydrogenation process involved an investment in fixed assets from $700 to $900 a barrel daily capacity, as compared with $300 to $500 for an ordinary refining and cracking plant.[5] Since that time, however, constant improvements in operating technique have reduced the cost of hydrogenating fuels, so that slight changes in economic conditions will justify the operation of such plants on a large scale. According to Nelson [6] the cost of hydrogenated gasoline when first produced was 20 cents a gallon, and in 1937 it was estimated that 10 cents a gallon would net a worthwhile profit. Although still in the stage of experimentation in the United States, it is technically possible to produce synthetic hydrocarbon products by applying the hydrogenation process to coal.

Some reductions in waste and in the cost of operation have been secured through increased size of refineries, changes in the design of plants, and the growing number of combination plants. Although crude-oil capacity of refineries in the United States showed a substantial increase during 1937, the total number of plants in March 1938 was less than at any time since 1932.[7] Individual refinery units capable of processing 10,000 barrels of crude oil in a day are becoming common, and units with a capacity of 30,000 barrels or more are in operation. Some refineries with multiple units have capacities of 150,000 barrels per day, or more. In one commercial operation it is possible to separate oil into a range of motor fuels, burning oils, gas oils, lubricating oils, and residue with conditions so controlled that they may be varied according to the kind of products required. As early as 1931, Camp [8] wrote that "it is not at all unlikely that a plant could be designed with balanced skimming, cracking, and hydrogenation facilities to manufacture whatever products are most desirable and in whatever percentages they are desired."

Major savings have been achieved in capital investments and labor and fuel-operating costs as a result of expansion of combination operations. Such units also have been increased in flexibility, with the result that crude oils of various types now are being used and the yields of finished products are adjusted to meet requirements. When cracking was first introduced, many units were required for the various operations of distillation, cracking, and rerunning; but with refinements in combination units, it is possible to combine all these processes in a continuous operation. Consequently, one crew of operators now can process as much oil and produce a greater quantity of gasoline than was possible in 1926 with several units and a large force of men.[9] Recently, a plant in which polymerization, cracking, and natural gasoline manufacturing are combined has been placed in operation.[10] Although the equipment for each operation is a separate unit, all are on the same site, and the products or byproducts of one unit are processed further in the others.

Although possibilities of producing good lubricating oil from the residual oil left after the removal of kerosene were recognized almost from the beginning, petroleum lubricating oils were not widely adopted until after 1885, and until 1900 virtually all petroleum lubricants were made from Appalachian crude oils. None of the crude oils processed by early methods yielded a lubricant having all the desired qualities. The lubricating distillate was "cut" from the still after the kerosene fraction had been removed and was chilled and passed through filter presses at a low temperature, securing an unfinished paraffin wax and a pressed distillate which was rerun to secure various grades of neutral lubricating oils. The residual oil in the still was steam refined, reduced to the desired viscosity, and finished as cylinder stock with acid treatment followed by neutralization and percolation through a tower filled with animal charcoal. Later, fuller's earth was used instead of animal charcoal. Lubricants made from one type of crude oil had a tendency to form carbon in cylinders of internal combustion engines and, because the crude oil contained rather large quantities of wax, low pour-point oils could not be made from it, whereas lubricants made from other oils showed low stability and rapid changes in viscosity with changes in temperature.

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[2] Hubner, W. H., and Egloff, Gustav, work cited in footnote 1.

Heron, S. D., "Effect of High Octane Fuel on Aircraft Operation," *Oil and Gas Jour.*, November 12, 1937, p. 185.

[3] Nelson, W. L., "What Refiners Have Not Effected," *Oil and Gas Jour.*, March 25, 1937, p. 83.

Oil and Gas Jour., "Shell Manufactures 100-Octane Motor Fuels on Large Scale." November 25, 1937, p. 108.

Brown, E. L., and Tilton, J. A., "Production of Aviation Fuel by High-Pressure Hydrogenation," *Oil and Gas Jour.*, March 31, 1938, p. 75.

McAllister, S. H., "Catalytic Polymerization of Butylenes by Sulphuric Acid." *Oil and Gas Jour.*, November 12, 1937, p. 139.

[4] Ellis, Carlton, "Trend in Petroleum Derivatives," *Oil and Gas Jour.*, April 14, 1938, p. 59.

[5] Fraser, C. E., and Doriot, G. F., *Analyzing our Industries*, New York, 1932, pp. 428–30.

[6] Nelson, W. L., "What Refiners Have Not Effected," *Oil and Gas Jour.*, March 25, 1937, p. 83.

[7] Stormont, D. H., "Refining Capacity Increased to New High by Plant Additions." *Oil and Gas Jour.*, March 31, 1938, p. 147.

[8] Camp, H. W., "Development in Refinery Engineering During 1930," *Pet. Dev. Tech., 1931, Am. Inst. Min. and Met. Eng.*, p. 646.

[9] Guthrie, B., Schimmel, H., Albright, J. C., Rogers, H. O., and Ross, J. S., "Technical Advances in Refining," *Technology, Employment, and Output per Man in Petroleum and Natural-Gas Production*, ch. X, Works Progress Administration National Research Project in cooperation with the Bureau of Mines, 1939.

[10] Stormont, D. H., "Cracking, Polymerization, and Natural Gasoline Recovery Combined in a Single Plant," *Oil and Gas Jour.*, March 31, 1938, p. 46.

Improved vacuum-distillation and fractionating equipment have made possible the more exact separation of primary lubricating-oil fractions and, therefore, made the removal of wax easier and reduced subsequent treating and finishing. Dewaxing operations, using the cold settling method, were improved by the introduction of the centrifuge, first used in 1920. Lubricating oils also are contacted with finely ground clay (200–300 mesh) at high temperatures to neutralize acidity and remove highly colored constituents.

The greatest recent improvement in the manufacture of lubricating oils is the application within the last 10 years of solvents of chemical reagents [11] which dissolve selectively those constituents of the oil that are undesired. These solvents have been adapted for three types of refining; solvent dewaxing, solvent extracting processes, and deasphalting processes. Extraction methods have progressed from the early method of contact in a single stage in an agitator to present methods of countercurrent treatment. Many different solvents are used and experiments are being conducted constantly in an effort to improve solvent refining.[12]

A demand of considerable magnitude has been developed for petroleum asphaltic products. These products include solid and liquid asphalts for paving, roofing asphalts, binders for briquetting coal and coke, waterproofing and pipe-coating preparations, and many other products.[13]

This brief résumé of progress in petroleum refining operations mentions some of the more important advances in the art. The industry is expending vast sums of money in research and development, and at the beginning of 1939 several new processes and improvements of older processes are being offered to petroleum refiners. The industry undoubtedly is only on the threshold of its development as a chemical-manufacturing enterprise, adapting to its own purposes discoveries in many fields of science as well as the discoveries of its own scientists and engineers. Future progress will proceed from continued exercise of the same kind of ingenuity, skill, and persistence, backed by deep study that has brought about the marvelous developments of the modern petroleum industry.

Conclusion

A review of salient methods and processes constituting phases of technology in the petroleum industry brings out several significant facts.

1. The art of finding commercial accumulations of oil and natural gas has become a highly specialized and scientific branch of the industry, requiring a high degree of technical training and calling for the expenditure of vast sums of money on the part of the operators to maintain their reserves of petroleum and natural gas.

2. The drilling of wells and the producing of oil and gas solely from the derrick floor is outmoded. Careful analyses of many kinds of technical data are making possible the continuing flow of oil and gas by reason of optimum utilization of reservoir energy, and ultimate recoveries are being increased. The data are being obtained by means of laboratory examination of reservoir rocks and fluids, the measurement of pressures, temperatures, and other conditions in the reservoirs, and the careful study of case histories of wells, properties, and fields. Applied engineering methods resulting from research have taken the place of rules of thumb.

3. The diversity and quantity of materials used in drilling a well and making it a "producer" have become greater not only with well depth but as knowledge has increased regarding requirements for coping with reservoir conditions. The broad field of chemical engineering now constitutes an integral part of production technique in preparation of mud fluids, cementing wells, treating formations with acids and other chemicals, and in many other ways to remove the oil and gas effectively and economically.

4. A large part of these essential operations are performed by so-called "service" companies that do not themselves produce oil and natural gas. The supply-

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[11] Kalichevsky, V., *Modern Methods of Refining Lubricating Oils,* Reinhold Publishing Corporation, New York, N. Y., 1938.

[12] Strang, L. C., "Current Research Work on the Solvent Refining of Motor Oil," *Oil and Gas Jour.,* March 25, 1937, p. 98.

McClure, W. B., Dickinson, J. T., and Forrest, H. O., "Refining of Pennsylvania Oils by Propane Process," *Oil and Gas Jour.,* March 31, 1938, p. 37, and October 27, 1938, p. 174.

Smoley, E. R., Shutte, A. H., and Davis, H. R., "Solvent Refining of Lubricating Oils," *Oil and Gas Jour.,* November 10, 1938, p. 37.

[13] Redfield, A. H., "Asphalt and Related Bitumens," *Minerals Yearbook, 1938,* Bureau of Mines, pp. 977–988.

ing of technical service or the service of tools and materials is an indispensable auxiliary found perhaps to no equal extent in any other industry.

5. Mass movement of liquids and gases over long distances has been made possible through metallurgical and mechanical achievement. The result is that pipe lines, supplemented by tankers, tank cars, and trucks constitute a great coordinated system of transporting facilities that are functionally as important to the industry and the public in maintaining an uninterrupted movement of petroleum and natural gas from wells to consumers as the blood-circulating system is in maintaining life in the human body.

6. Refineries have grown from simple stills whose chief product was illuminating oil to great establishments manufacturing hundreds of products. The complexities of all the processes are not within the grasp of any one person. The rearrangement of hydrocarbon molecules of the crude oil and refinery gases by suitable applications of heat and pressure, sometimes aided by catalysts, has made possible yields of gasoline and other products that the early distillers would have said were impossible. At times this ability to supply has outdistanced facilities to use the products. With this prompting, the design of internal combustion engines, lubricating equipment, and oil-burning mechanisms have been improved. Today the elasticity of well-balanced refinery operations makes possible the manufacture of desired products in quantities to meet the current need.

PART THREE—SECTION III
CONSERVATION IN USE

By A. C. Fieldner,[1] F. G. Tryon,[2] and H. F. Yancey[3]

Striking advances have been made in the efficiency of fuel utilization as compared with the disappointingly slow progress made in checking wastes during production. The contrast between lack of conservation during production and the increasing efficiency of utilization is due in large part to the fact that in the present organization of production the incentive to minimize waste is often lacking. Scattered ownership of oil and gas resources stimulate competitive drilling, tend to reduce ultimate recovery, and discourage profitable operation. In coal mining destructive competition and the resulting unstable economic position of the industry tend to accentuate rather than to minimize the waste of this resource. In the field of utilization, however, the same forces, competition, and the necessity of profitable operation, act in a socially useful direction to promote economy in use.

Rise in Fuel Technology

Increased efficiency in utilization, whereby less fuel is required to produce a unit of finished product, has been especially rapid in the last 30 years. In large part this rapid advance must be attributed to the acquisition and use of the scientific knowledge of fuels made available to the increasing numbers of technically educated persons employed in industry. Knowledge of the composition and properties of solid, liquid, and gaseous fuels is necessarily fundamental to any increase in their efficiency of utilization. Although progress in fuel utilization in the United States may be considered as beginning with a series of steaming tests of different coals conducted for the Navy Department by Professor Johnson in 1844,[4] the date of rapid progress in increased efficiency in using coal—the first industrial fuel—should be considered as beginning with the first Nation-wide survey of the composition and properties of American coals made by the United States Fuel Testing Plant established by the Federal Geological Survey at the Louisiana Purchase Exposition in St. Louis, Mo., in 1904. Other landmarks of this early period were the National Conservation Congress of 1908 and the organization of the International Railway Fuel Association.

The work of the Federal Geological Survey at St. Louis included the sampling and analysis of many coal beds throughout the United States. In addition, carload samples of commercial sizes of coal were sent to the fuel-testing plant for combustion, carbonization, gasification, briquetting, and washing tests in full-scale equipment. Research was conducted on the relation between physical and chemical properties of the different ranks and groups of coal and their various uses. This work stimulated so much interest in the more efficient utilization of our mineral-fuel resources that it was continued by the technologic branch of the Survey, and subsequently by the Federal Bureau of Mines after its creation in 1910. Preliminary large-scale tests of the steaming, coking, and gasifying properties of many important American coals were fairly well completed by 1915. The results of these tests and investigations were published by the Bureau of Mines in a series of reports,[5] and have been followed in later years by an unending volume of carefully prepared technical reports dealing with investigations of many phases of coal technology, which up to 1935 alone have totaled 1,895 in number and required 93 pages of a technical paper to list the titles.[6] These publications have been of great value to American industry. The early reports stimulated a widespread interest in fuel economy and provided the fundamental data necessary to the spectacular increases in fuel efficiency which took place in the following decade.

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[1] Chief, Technologic Branch, U. S. Department of the Interior, Bureau of Mines.

[2] Director, Division of Research, National Bituminous Coal Commission.

[3] Supervising Engineer, Northwest Experiment Station, U. S. Department of the Interior, Bureau of Mines.

[4] Johnson, W. R., 28th Cong., 1st sess., S. Doc. 386, p. 844; see also Parr, S. W., Ind. and Eng. Chem., vol. 18, 1926, pp. 94–98.

[5] Belden, A. W., Delameter, G. R., Groves, J. W., and Way, K. M., *Washing and Coking Tests of Coal at the fuel-testing plant, Denver, Colo., July 1, 1908, to June 30, 1909,* Bureau of Mines, Bull. 5, 1910, 62 pp., 1 fig.

White, A. H., and Barker, Perry, compiled and revised by Wilson, H. M., *Coals Available for the Manufacture of Illuminating Gas,* Bureau of Mines, Bull. 6, 1911, 77 pp., 4 pls., 12 figs.

Fernald, R. H., and Smith, C. D., *Résumé of Producer-Gas Investigations, October 1, 1904, to June 30, 1910,* Bureau of Mines, Bull. 13, 1911, 393 pp.

Breckenridge, L. P., Kreisinger, Henry, and Ray, W. T., *Steaming Tests of Coals and Related Investigations, September 1, 1904, to December 31, 1908,* Bureau of Mines, Bull. 23, 1912, 380 pp., 2 pls., 94 figs.

Randall, D. T., and Weeks, H. W., *The Smokeless Combustion of Coal in Boiler Furnaces,* with a chapter on "Central Heating Plants," Bureau of Mines, Bull. 40, 1912, 188 pp., 40 figs.

Wright, C. L., *Fuel-Briquetting Investigations, July 1904 to July 1912,* Bureau of Mines, Bull. 58, 1913, 277 pp., 21 pls., 3 figs.

Ovitz, F. K., *Coking of Illinois Coals,* Bureau of Mines, Bull. 138, 1917, 71 pp., 11 pls., 1 fig.

Belden, A. W., *Metallurgical Coke,* Bureau of Mines, Tech. Paper 50, 1913, 48 pp., 1 pl., 23 figs.

[6] Fieldner, A. C., Emery, Alden H., and von Bernewitz, M. W., *Bibliography of United States Bureau of Mines Investigations on Coal and Its Products 1910–35,* Bureau of Mines, Tech. Paper 576, 1937, 145 pp.

Although these Governmental activities, and the work of the few technical colleges that carried on fuel research in early years, provided the essential foundation, nevertheless the adoption and actual use of the fundamental data by industry was no doubt chiefly the result of economic pressure. Progress along these lines was enormously stimulated by the high prices of fuel in the war period. The impetus gained during the war was reinforced by intensified competition in post-war decades. The over-all result was a remarkable burst of technological activity.

Centralized Services

Before considering the various lines of advance recorded in the utilization of fuel, the relative importance of the various forms of fuel should be considered. Table 1 shows a percentage distribution of the total energy supply for the mineral fuels—coal, both anthracite and bituminous, petroleum, natural gas, and the fuel equivalent of water power.[7] These figures indicate that although the percentage of the total energy contributed by coal has decreased decidedly since 1899, it still remained the largest source of energy in 1937, when it furnished 53.7 percent of the total. Petroleum has contributed a steadily increasing percentage during this same period; nevertheless, the total provided by the mineral fuels—coal, petroleum, and natural gas—has remained substantially the same throughout the entire period. Due primarily to the increased efficiency at which coal is utilized in central stations, the rate of growth of water power is obscured in table 1, because water power is represented by the equivalent coal that would have been needed in any one year to generate the same power at a steam-electric station.[8]

TABLE 1.—*Percent of total B. t. u. equivalent contributed by the several mineral fuels and water power in the United States*

Year	Pennsylvania anthracite	Bituminous coal	Total coal	Petroleum (total crude)[1]		Natural gas (total production)[1]	Total oil and gas	Total mineral fuels	Water power, fuel equivalent[2]	Grand total, including water power
				Domestic production	Imports					
1899	21.8	67.3	89.1	4.5	----------	3.2	7.7	96.8	3.2	100.0
1909	15.4	69.7	85.1	7.7	----------	3.6	11.3	96.4	3.6	100.0
1913	13.0	70.3	84.2	8.3	0.6	3.5	12.4	96.6	3.4	100.0
1918	12.4	69.9	82.3	9.9	1.0	3.6	14.6	96.8	3.2	100.0
1920	11.0	67.0	78.0	12.0	2.9	3.8	18.7	96.7	3.3	100.0
1925	7.6	61.3	68.9	20.6	1.7	5.8	28.1	97.0	3.0	100.0
1929	7.9	55.1	63.0	23.8	1.9	8.1	33.8	96.8	3.2	100.0
1930	8.3	53.9	62.2	23.7	1.6	9.2	34.5	96.7	3.3	100.0
1931	8.3	51.3	59.6	26.2	1.5	9.3	37.0	96.6	3.4	100.0
1932	8.1	48.2	56.3	28.0	1.6	9.9	39.5	95.8	4.2	100.0
1933	7.4	48.4	55.8	30.0	1.1	9.2	40.3	96.1	3.9	100.0
1934	8.1	49.0	57.1	28.3	1.1	9.9	39.3	96.4	3.6	100.0
1935	7.0	48.3	55.3	29.5	1.0	10.2	39.8	96.5	3.5	100.0
1936	[3] 6.5	50.2	56.7	28.8	.8	9.8	39.7	96.4	3.6	100.0
1937 [4]	[3] 5.7	48.0	53.7	31.7	.7	10.4	42.8	96.5	3.5	100.0

[1] Irrespective of future use: for example, includes Diesel oil, gasoline, lubricants, and carbon black.

[2] Water power computed at prevailing central-station equivalent for year.

[3] If bootleg coal were included the proportion from anthracite would be 6.7 in 1936 and 6.0 in 1937 at prevailing water-power equivalents.

[4] Preliminary.

The rise of centralized services for the conversion of raw fuel into heat and power has been a process of continuous evolution. We are moving from the simple economy of a hundred years ago, when the consumer received chunks of raw fuel and made his own heat and power, to an ultimate highly articulated economy wherein the consumer rarely sees the raw fuel and is served by an intermediary utility. The utility receives raw fuel and converts it into delivered heat or power, all at great savings in unit consumption. As an example, the output of electrical energy for public use increased from 2.5 billion kilowatt hours in 1902 to over 117 billion in 1937,[9] breaking all previous records. More than 82 percent of industry is now electrified and many of the individual industrial units purchase central-station power. As is well appreciated, tremendous growth in the use of power in the form of electricity and gas has also taken place in the household.

Increases also have occurred over the years in the field of district heating by means of steam. However, in recent years such heat furnished by the public-utility companies presented no noticeable changes. Although there was a moderate amount of line extension in several cities, activities were reported to be confined mainly to routine operation and service.[10]

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[7] Tryon, F. G., Mann, L., and Young, W. H., "Coal," Bureau of Mines, *Minerals Yearbook, 1937*, p. 810, and *1938*, p. 701.

[8] For full information on this question see McMillan, M. E., Anderson, R. L., Tryon, F. G., and McBride, J. W., "Bituminous Coal," Bureau of Mines, *Minerals Yearbook, 1938*, p. 701.

[9] "Electric Light and Power," Bureau of Foreign and Domestic Commerce, *Survey of Current Business*, vol. 18, no. 3, 1938, p. 29.

The field of utilities supplying heat by means of either high- or low-pressure steam is limited to urban areas having a high density of space to be heated, such as office buildings, hotels, and apartments. Generally it is not considered economical to furnish steam heat to detached dwellings from a central plant in the district. Modern stoker-,[11] oil-,[12] and gas-fired residential heating plants operate more efficiently than hand-fired furnaces.

Processing of Raw Fuel

Seventy years ago iron was smelted largely by raw coal and virtually all other fuel was burned in the raw state. Now coke has entirely supplanted coal as a blast-furnace fuel except at a few isolated furnaces. This change is primarily responsible for the growth of coal carbonization, as evidenced by the production of 52 million tons of coke in 1937—the largest amount since 1929.

High-temperature carbonization.—Loss of valuable byproducts in the combustion of raw bituminous coal has been a favorite subject of discussion for many years in connection with the conservation of coal. It is pointed out that the coke, gas, tar, light oil, and ammonia obtained in the distillation of a ton of coal have a greater value than the raw coal from which they are obtained. This statement is true only within the limitations of the available market for these products, and unfortunately the United States does not provide a large market for the byproducts of coal distillation. Only 48 percent of the 603,053,288 gallons of tar produced in 1937 was sold for refining into tar products. The remainder was used as fuel, principally by the producers in the open-hearth furnaces of affiliated steel plants. The average value of the tar sold was $0.048 per gallon.

Light oil has a better market than tar. The excess not required for refined benzol, toluol, xylol, etc., is readily absorbed in the production of antiknock motor fuel. But there, also, the price realization is low, due to the low price of gasoline. Approximately one-half of the 187,054,346 gallons of crude light oil produced in 1937 was refined into benzol, toluol, xylol, and solvent naphtha, and the remainder was refined for motor fuel. The average sales price of the motor benzol at the coke-oven plants was $0.089 per gallon.

Ammonium sulphate, formerly one of the most remunerative byproducts, brought an average return of only $0.014 a pound. Gas is the only coke-oven byproduct that has not declined in value during the last decade. The average value of the coke-oven gas sold in 1937 was $0.158 per 1,000 cubic feet. The average receipts per ton of furnace, foundry, and water-gas coke sold in 1937 were $4.22, $7.91, and $6.25, respectively.[13]

It is evident from these figures that the financial return from byproducts offers comparatively little incentive for carbonizing coal in the United States except where there is an active demand for the coke. This is due to the abundance of petroleum and natural gas, which effectively compete with the byproducts of coal carbonization. The low price of natural and refinery gases, fuel oil, and gasoline reduces the return from coal gas, tar, and light oil to the point where these products cannot pay the cost of carbonization, except under special and limited conditions. Also the development of processes for synthesizing ammonia from nitrogen and hydrogen has reduced the price of this byproduct to the point where it barely covers the cost of recovery from coal gas. Under these conditions the carbonization of coal in the United States depends mainly on the market for coke.

The decline in the beehive process of producing coke was greatly accelerated by war demands for benzol and toluol—produced from the distillation of coal in byproduct ovens—in the period from 1914–19. Following this period, byproduct-oven plants were erected in a number of the larger cities for producing city gas coincident with the supplying of coke for domestic heating. Gas companies gave special attention to preparing coke in the sizes most suitable for domestic heating, and they conducted educational campaigns on methods of burning coke in house-heating furnaces. As a result, the use of domestic coke continued to increase until recently. No doubt this increase would have been greater but for unexpected revival of competition from natural gas. Completion of long-distance pipe lines, extending as many as 1,000 miles from the prolific southwestern gas fields to the central and much of the eastern United States in the years following 1928 entirely stopped further expansion of the coal-gas industry.

Low-temperature carbonization.—For domestic heating purposes, ease of ignition and high combustibility are not so important in furnace fuel as in fuel for open-grate fires. Therefore, the incentive to manufacture low-temperature coke is not so great here as in England. Nevertheless, large sums have been spent in the United States in attempting to develop a low-temperature carbonization industry. Most of the processes and two large commercial plants have failed. However, three low-temperature processes have survived the depression and have operated more or less intermittently on a commercial scale. Lehigh Briquetting Co. at Dickinson, N. Dak., has increased the capacity of its plant for the carbonization of lignite by the Lurgi process to 60,000-70,000 tons of briquets per year.

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[10] Competition in House-Heating and Activity in Minimum Standards Emphasized in '38," *Heating and Ventilating*, vol. 36, January 1939, p. 35.

[11] Yancey, H. F., Johnson, K. A., Lewis, A. A., and Cordiner, J. B., Jr., *Burning of Various Coals Continuously and Intermittently on a Domestic Overfeed Stoker*, Bureau of Mines, Report of Investigations 3379, January 1938, 30 pp.

[12] Senner, Arthur H., *A Study of the Oil Burner as Applied to Domestic Heating*, U. S. Dept. of Agriculture Tech. Bull. 109, 1938, 44 pp.

[13] Bennit, H. L., Bureau of Mines, *Coke and Byproducts Tables, 1937*, Mimeographed October 15, 1938, 29 pp.

The Pittsburgh Coal Carbonization Co. has developed the Wisner process to a full commercial scale and is now operating three rotary units at its Champion No. 1 cleaning plant near Pittsburgh, Pa. The combined capacity of the three units is 325 short tons of coal per day. The coke produced does not require briquetting and issues from the retorts in the form of strong, dense balls up to 6 inches in diameter. This fuel is easily ignitible, essentially smokeless, and contains 15 to 18 percent volatile matter. It is sold regularly in a number of cities and seems to find a ready market at about the same price as high-temperature coke. The raw coal used in the process is cleaned fine-sized coal from the washery, which is difficult to market as such. Hence this operation is in the interest of conservation since it produces a high-grade fuel from a material otherwise difficult to sell.

The usual byproducts of gas, tar, and light oil are recovered in all of these processes, but on account of their low value, determined by the competition of natural gas and petroleum, it is obvious that the economic survival of these low-temperature processes depends largely upon the differential between sales realization of the low-temperature coke and that of the raw material carbonized.

Medium-temperature carbonization.—No medium-temperature carbonization processes such as that of H. Koppers, of Germany, have been introduced in the United States. However, the Curran-Knowles sole-flue ovens, which were installed in 1933 by the Radiant Fuel Corporation at West Frankfort, Ill., produce a coke that is a mixture of high- and medium-temperature coke by heating the horizontal charge from the bottom only. This process appears to have some advantage in the production of an easily combustible smokeless fuel from poorly coking coals or difficulty marketable fines that are not capable of being handled in the usual vertical type byproduct oven. The West Frankfort plant, consisting of 26 ovens, has a capacity of 300 tons of coal per day.

Complete gasification.—The production of producer gas for power and heating furnaces has declined steadily in the United States, due to the increasing abundance of natural gas and petroleum. Also, ovens for the production of metallurgical coke usually are installed at the steel plants, and the byproduct gas and tar are used instead of producer gas for heating metallurgical furnaces.

Likewise, the manufacture of carbureted water gas for city gas has suffered from the inroads of natural gas, petroleum refinery gases, and the propane and butane fractions of natural gas. These developments have conserved natural gas and petroleum products formerly wasted, and therefore are on the credit side of the national fuel ledger; but they have added to the economic difficulties of the coal industry by reducing the demand for the products of coal carbonization and gasification.

Hydrogenation of coal.—The United States with its tremendously developed petroleum industry has not yet felt the need for producing liquid fuels from coal. Undoubtedly the time will come when the decline in the discovery of new pools of petroleum will require supplementary sources of motor fuel. Such sources are available in large reserves of bituminous and subbituminous coal, lignite, and oil shale. These materials are widespread in the United States and all of them are amenable to hydrogenation.

An experimental plant for the continuous hydrogenation of about 100 pounds of coal per day has been installed at the Pittsburgh Station of the Federal Bureau of Mines for determining the amenability of different ranks and types of American coals to liquefaction by hydrogenation. So far experimental runs have been made on coals from the Pittsburgh bed in Pennsylvania and the No. 6 bed in Illinois. Additional coals to be put through the plant in the immediate future include a high volatile bituminous coal from Washington, a subbituminous coal from Colorado, and a lignite from North Dakota. Work on the Pittsburgh bed coal showed that it was possible to liquefy about 75 percent of the coal (moisture- and ash-free basis). The liquid portion consisted of equal quantities of light oil and heavy oil.[14]

Growth of petroleum refining.—At the beginning of the fuel economy movement 30 years ago, the petroleum industry was in what has been aptly called the "kerosene age"[15] because this was the principal product desired by the oil refiner. Kerosene was then called "coal oil" because it was first produced by the distillation of coal. With the discovery of petroleum in Pennsylvania by Drake in 1859, many of the 60 coal-distillation plants were adapted to the processing of petroleum.[16] The transition from the kerosene to the gasoline age resulted, of course, from the increased use of the automobile and from about 1912 the petroleum refining industry increased rapidly. In 1908, 83 percent of the 178-million-barrel production of petroleum was refined. In recent years, from 90 to 98 percent of the 1-billion-barrel production has been so treated. However, the principal changes that have come about with the growth of petroleum refining, aside from the tremendous increase in production, have been the technologic advances which allow the refiner to increase the yield of the particular product or variety of products demanded by the market. Table 2 shows the changes that have occurred in the yields of products for 3 selected years—1909, 1920, and 1937.

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[14] Storch, H. H., Hirst, L. L., Golden, P. L., and others, "Coal Hydrogenation, U. S. Bureau of Mines Experimental Plant," *Jour. Ind. and Eng. Chem.*, vol. 29, 1937, pp. 1377-1380.

[15] Egloff, Gustav, *Earth Oil*, Williams and Wilkins Co., Baltimore, 1938, p. 125.

Especially significant with the passage of time are the decreasing percentage of kerosene and the increasing amounts of gasoline. Comparatively recent technical developments, such as the use of the hydrogenation process for crude oil and the reforming of the lighter fractions of petroleum by polymerization into gasoline of high antiknock value, may be regarded as conservation measures because of the facility with which changing market demands may be met and also because increased efficiency of utilization becomes possible.

TABLE 2.—*Percentage yields of refined petroleum products in the United States*

Product	Year		
	1909 [1]	1920 [2]	1937 [3]
Kerosene or illuminating oil	37.9	11.3	5.5
Gasoline	11.7	19.5	43.9
Gas oil and distillate fuel oil	-------	-------	12.4
Gas oil and fuel oil	-------	48.6	-------
Residual fuel oils	33.6	-------	26.2
Lubricating oils	10.6	-------	-------
Greases	.1	-------	-------
Lubricants	-------	5.7	3.0
Wax	.9	.4	.1
Coke	-------	.8	.5
Asphalt	-------	1.9	2.0
Road oil	-------	-------	.7
Still gas	-------	-------	5.2
Other and losses	5.2	11.8	.5

[1] *Mineral Resources of the United States, 1910,* Geological Survey, pt. II, p. 357.

[2] Computed from data given in *Mineral Resources of the United States, 1924,* pt. II, Bureau of Mines, p. 455.

[3] *Minerals Yearbook, 1938,* Bureau of Mines, p. 862.

Natural gas.—The volume of natural gas sold in the United States has increased from 481 billion cubic feet in 1909 to 2,370 billion cubic feet in 1937, approximately a fivefold increase.[17] The principal uses are in field operation, the manufacture of carbon black (a nonfuel use), as fuel for petroleum refineries and electric public utility power plants, as fuel for the manufacture of Portland cement, processing for the recovery of natural gasoline, and for domestic and commercial consumption. For the latter purpose, it is often used to enrich manufactured gas. The consumption of such mixed gases is increasing in large population centers with the growth of long-distance interstate pipe-line transportation. Domestic consumption of natural gas was 364 billion cubic feet in 1937, or about 15 percent of the total marketed production. Commercial users took 5 percent of the total production and industrial users 80 percent.

Fuel briquets.—The manufacture of fuel in lump form from fine-sized material may be regarded as a process operation, although the fuel itself is unchanged, chemically, except as it may be more efficiently utilized in a coarser-sized form. Although the briquetting of fuel, principally of low-volatile coal and of small amounts of carbon produced in the manufacture of gas from petroleum, has been increased markedly during the past 30 years—from 66,524 tons in 1907 to 995,930 in 1937,[18] briquetting in the United States has never become as important an industry as it has in Europe. The 1937 world production data are incomplete, but the production in the most important briquet-making foreign countries (Germany, France, and Belgium) totaled about 69 million tons as compared with less than 1 million tons in the United States.

In recent years paper-wrapped cubes of coal, prepared by compressing raw screenings with a small amount of starch binder and water, have been marketed in increasing quantities by retail coal yards as packaged fuel; the paper-wrapped packages usually contain six 3- to 4-inch cubes and weigh from 10 to 15 pounds. In 1937, 64 manufacturers produced 146,037 tons, principally in the States of Michigan, Iowa, Wisconsin, and Minnesota.[19]

Mechanical cleaning of coal.—Prior to 1920 mechanical cleaning of bituminous coal to reduce its ash and sulphur content was confined largely to that used for the manufacture of metallurgical coke. Since that time the keen competition caused by excess mine capacity and the introduction of mechanical methods of mining and loading has led to the use of wet and pneumatic methods of cleaning coal for general industrial and domestic use as well. The percentage of the total production of bituminous coal cleaned has increased from 5.3 percent in 1927 to 14.7 percent in 1937.[20] This trend has favored conservation, since mechanical cleaning has made it possible to crush the lumps of impure coal discarded on the picking table and to recover the considerable quantity of fuel they contain. At the same time the cleaner product obtained can be utilized with greater efficiency. Clean coking coal produces less wastage in coke breeze [21] and reduces clinker trouble in gasification. Modern coal-washing plants operate under careful scientific control. Their products are of uniform composition from day to day. This uniformity of composition promotes efficient utilization, and, finally, there is a material saving in transportation charges per unit of energy by elimination of the useless ash-forming material discarded as refuse.

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[16] Nelson, W. L., *Petroleum Refinery Engineering,* McGraw-Hill Book Co., 1936, p. 5.

[17] McBride, R. S., and Sievers, E. G., "Natural Gas in 1919–1921," Geological Survey, *Mineral Resources of the United States, 1921,* pt. II, p. 341, and Lott, F. S., and Hopkins, G. R., "Natural Gas," Bureau of Mines, *Minerals Yearbook, 1938,* p. 907.

[18] Goodman, G. S., "Fuel Briquets and Packaged Fuel," Bureau of Mines, *Minerals Yearbook, 1938,* pp. 795 and 803.

[19] *Ibid.,* footnote 18, p. 795.

Efficiency in consumption.—All of the processing developments previously discussed tend to save fuel but at the same time they intensify competition between rival sources of energy. Much of the advance in fuel technology has of course been devoted to improving performance rather than to reducing unit consumption. A conspicuous example is the motor car. American designers have emphasized speed, power, and acceleration rather than fuel economy. The mileage per gallon has not increased as much as power has been stepped-up with the same unit consumption in order to increase performance.

In other fields of industry there has been extraordinary progress in the reduction of fuel consumption per unit of product. This increase of efficiency since the advent of the mechanical age has aided greatly in conserving our mineral fuel resources. The trend toward increasing efficiency has been marked in both domestic and industrial lines, but strikingly in the field of power production from coal, as is shown in table 3.

As illustrated, the pounds of coal consumed per kilowatt-hour generated have decreased from 6.4 in 1902 to 1.44 in 1937, a reduction of 77.5 percent. Similar, though less marked, coal savings have occurred in railroad transportation, in iron blast-furnace smelting, and in coke manufacture. Table 4 shows the progress of fuel economy for these industries for 1919, 1926, and 1937 in comparison with electric public utility power plants for the same years.

Although industries that burn coal have made the greatest strides in increased efficiency of utilization, significant improvements also have taken place in the fuel economy of petroleum refineries. In 1919, 849,000 B. t. u. represented the energy consumed in refining one barrel of crude petroleum. In 1937 this figure dropped to 554,000 B. t. u.,[22] a saving of 34.7 percent.

The combined savings in transport and industry have probably averaged 40 percent between 1908 and 1938. This is more than in any equal period of time except the years immediately following Watts' development of the steam engine. These savings are due less to a few epoch-making inventions than to the cumulative effect of many small economies. Although the rate of fuel saving in large central power stations is now slowing down, large additional savings are assured in bringing average performance nearer the level of the best present performance.

TABLE 3.—*Progress of fuel efficiency as indicated by the average consumption per kilowatt-hour of electric public utility power plants in the United States, 1902–37* [1]

Year	Coal consumed per kilowatt-hour generated [2]	Year	Coal consumed per kilowatt-hour generated [2]
	Pounds		*Pounds*
1902	6.4	1927	1 84
1907	5.4	1928	1.76
1912	4.5	1929	1.69
1917	3.47	1930	1.62
1919	3.22	1931	1.55
1920	3.04	1932	1.50
1921	2.73	1933	1.47
1922	2.61	1934	1.47
1923	2.41	1935	1.45
1924	2.22	1936	1.45
1925	2.07	1937	1.44
1926	1.95		

[1] Figures for 1902–17 from a special study by F. G. Tryon for the Brookings Institution. *Transactions, Second World Power Conference*, Berlin 1930, vol. VI, pp. 244, 245; those for 1919 to 1935, from A. H. Horton, Division of Power Resources, U. S. Geological Survey; those for 1936 and 1937 from Bureau of Mines, *Minerals Yearbook, 1938*, p. 692.

[2] Includes coal equivalent of oil, gas, and wood.

The cumulative effects of all fuel economies have been more than incidental repercussions so far as the coal industry is concerned, but adverse effects will be outweighed ultimately by permanent benefits. Nevertheless, advances in fuel economy, although contributing to the instability of coal production, have at the same time caused a reduction in the delivered cost of energy and, most importantly, resulted in prolongation of the life of underground fuel reserves.

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[20] Young, W. H., Mann, L., Bennit, H. L., and Tryon, F. G., "Coal." Bureau of Mines, *Minerals Yearbook, 1935*, Statistical Appendix, p. 275, and *Minerals Yearbook*, 1938, p. 689.

[21] Fieldner, A. C., *Influence of Washing Coal on Coke Properties and on Gas and Byproduct Yields*, Bureau of Mines, Report of Investigations 3020, 1930, 13 pp., and Report of Investigations 3114, 1931, 9 pp.

[22] Hopkins, G. R., *Progress of Fuel Economy at Petroleum Refineries in the United States*, Bureau of Mines, Rept. of Investigations 2829, 1927, p. 2, and Hopkins, G. R., *Survey of Fuel Consumption at Refineries in 1937*, Bureau of Mines, Rept. of Investigations 3430, 1938, p. 1.

TABLE 4.—*Indicators of the effect of fuel economy on consumption of coal per unit of performance since the World War*[1]

	Pounds	Reduction
Steam railroads:		
Pounds per 1,000 gross ton-miles freight service:		*Percent*
Average, 1919–20	170	
Average, 1936	119	30.0
Average, 1937	117	31.2
Pounds per passenger-train car-mile:		
Average, 1919–20	18.5	
Average, 1936	15.3	17.3
Average, 1937	15.1	18.1
Iron and steel—pounds coking coal per ton of pig:[2]		
1918	3,577	
1936	2,901	18.9
Coke manufacture: Savings of heat values through recovery of gas, tar, light oils, and breeze by extension of byproduct in place of beehive coking, 1913–36, expressed as percent of coal used for all coke in 1936[3]		20.2
Electric-public-utility power plants:		
Pounds per kilowatt-hour, 1919	3.2	
Pounds per kilowatt-hour, 1936	1.4	56.2
Pounds per kilowatt-hour, 1937	1.4	56.2

[1] From McMillan, M. E., Anderson, R. L., Tryon, F. G., McBride, J. W., "Bituminous Coal," Bureau of Mines, *Minerals Yearbook, 1938*, p. 716.

[2] Includes only savings through higher yields of merchantable coke per ton of coal charged and lower consumption of coke per ton of iron. Excludes economies through recovery of byproducts, which are treated in next item.

[3] These byproducts are used in part for boiler fuel, in part for metallurgical purposes, in part for domestic heating and cooking, and to a small extent for automotive fuel.

Use Selection of Fuels

Although the economic incentive of cost saving works effectively to promote fuel economy, it contributes little toward guiding the substitution of low-grade resources for the short-lived, high-grade ones. Fuel technology has nevertheless pointed out, in part, the means of using the abundant low-grade resources, and, at the same time, has been equally active in showing how better results may be obtained from the more limited high-grade resources. From the standpoint of economic utilization, the advantage generally remains with the high-grade material.

The consumer responds to the incentive of price, but he naturally seeks the immediate bargain in heat units with little consideration of long-time effects. The cost-saving incentive is sensitive to the immediate advantage and is generally blind to distant effects.

Developments of the future in fuel utilization in the United States depend to a large degree on the extent of the supply of petroleum, natural gas, and water power. Reduction of waste in the refining of oil and gas is still in progress, as, for example, the large-scale production of "polymer" gasoline from refinery gases, propane, and butane during the past years, and the more recent catalytic cracking processes. Long-distance natural-gas pipe lines are not as yet working at full capacity. The number of Diesel engines is increasing rapidly, and large hydroelectric projects are being built at an increasing pace. Certainly, there is no prospect for a relative increase in the demand for coal in the immediate future. In the more distant future, coal will be required to supplement and ultimately to replace petroleum and natural gas. As supplies of oil from national reservoirs begin to fail, the United States may turn to its larger reserves of oil shale. The great reserve of motor fuel, however, lies in the huge store of coal, suitable for treatment by hydrogenation and synthesizing processes.

In the meantime, coal on the average remains our cheapest fuel, and for this reason alone it must retain a substantial position in the Nation's fuel supply. Research and invention should develop further economy and convenience in utilization. In fact, the national energy economy demands that technological research should be centered on coal so that it can meet all of the Nation's requirements which do not specifically demand a liquid fuel. The petroleum supply should be reserved for those special automotive needs that can be served best by a liquid fuel, thus delaying as long as possible the day when motor fuel must be made from coal at necessarily higher costs.

From the longer range viewpoint of the Nation as a whole, consideration should be given within commonsense limits to the reservation of oil primarily for motor fuel and lubricants with discouragement of its indiscriminate use as boiler fuel, especially in regions of the country where coal is readily accessible. Similarly, natural gas might well be reserved for domestic and specialized industrial uses, including conversion into chemical products in regions where coal is not plentiful. Coking coals, low in sulphur content, should be reserved for metallurgical use; especially the high-grade coking coals, which are relatively scarce, should be blended with poor coking coals for such use. The use of all other coals for steam generation should be encouraged.

Obviously, such long-range objectives in the conservation of our fuel resources cannot be allowed to obscure completely our present-day necessities, but they deserve consideration even in the day-to-day decisions of public administration. The largest savings can be made in the field of production rather than of consumption. Sumptuary regulations offer little of value. Public policy in the realm of fuel consumption should center on stimulation of research and the widest possible dissemination of technologic improvements.

Organization of Fuel Research

Organized fuel research in the United States with a view to conserving fuel resources on a national scale began with the establishment of the United States fuel-testing plant at the Louisiana Purchase Exposition in St. Louis, Mo., in 1904. The boiler- and furnace-efficiency experiments conducted with various coals demonstrated great possibilities in saving coal by better combustion, and stimulated private industry in further developments and improvement of power-plant equipment.

Government fuel research initiated by the fuel testing plant has been continued and amplified by the United States Bureau of Mines through subsequent years and up to the present time. Other public agencies, notably the technical schools and the State engineering experiment stations, carry on research in this field and educate young engineers, who, entering the employ of industry, put into practice the idea of greater efficiency in the utilization of fuel for the production of heat and power.

The various petroleum and gas companies and affiliated national societies, the manufacturers of power-plant equipment, the larger fuel-using corporations, and the public utilities in particular have established technical research departments which in the aggregate have made enormous strides in practical fuel conservation by increasing the efficiency of utilization.

In the last decade, when further advancement has called for more intensive effort, industry has responded by financing research by well-coordinated, scientific research laboratories such as the coal research laboratory of the Carnegie Institute of Technology at Pittsburgh, Pa.; the research laboratory of the Anthracite Institute at Primos, Pa.; the fuel research groups of Bituminous Coal Research, Inc., at Battelle Memorial Institute, Columbus, Ohio, and at the mineral industries experiment station, State College, Pa.; and research fellowships at Mellon Institute, Pittsburgh, Pa., and at various universities. In the interest of conservation, such investigations should be continued and enlarged. The problems are many and varied in nature, and best results will be obtained by conducting widespread research at many places.

Use Economy and Resource Value

The remarkable advances made in the efficiency of utilization of coal and other fuels, while acting to prolong the life of the national reserves, also emphasize the importance of conservation in mining itself. By increasing the number of horsepower-hours that can be developed from 1 ton of coal, the fuel technologist makes it more worth while to recover that ton than to waste it underground. The trend of the dollar price of raw fuel does not give the full measure of its value. A decline in price may mean chiefly that the mining engineer has found ways of getting the fuel out with less labor than before. Another test is the number of horsepower-hours that can be got from the fuel. If that is doubled, the potential use value of the raw fuel is also doubled in a special but very real sense.

The advance of technology tends to multiply this potential use value, even though at times it has acted to depress the money price. The immediate effect of increasing efficiencies in combustion may be to curtail the quantity of raw fuel used, but the long-time effect is to stimulate the consumption of energy and thereby to put a premium on the usefulness of fuel and to bring it into wider service. The long-time result is clearly to enhance the inherent value of the resource.

An illustration of this tendency is the evolution of the internal combustion engine. Its advantages in flexibility, which so greatly stimulated the demand for petroleum, at first appeared to encroach upon the inherent utility of coal, but now that technology has found ways of converting coal into motor fuel, the potential usefulness of coal is magnified. Other examples might be cited of the way that technological progress in the application of one fuel may contribute to the potential value of another: Hydrogenation was developed in Germany as a means of making motor fuel from coal, but it has found its chief application in the United States in increasing the yield of gasoline from petroleum. Technology is tending to make the several forms of fuel more nearly interchangeable and more directly competitive. It is, of course, conceivable that science may some day develop sources of energy cheaper than mineral fuel, but we may be quite certain that it will find ways of getting greater utility from mineral fuel. It will, for example, find manifold uses for oil, gas, and coal as raw materials of manufacture in addition to their primary role as sources of heat and power.

Because of these advances in the technology of consumption, the inherent use value of the raw fuel steadily appreciates. In 1902, when the first census of the electrical industries gave an authentic picture of the average consumption of fuel per unit of power generated, it required an average of 6.4 pounds of coal to develop 1 kilowatt-hour. The engineering advances which have cut this requirement to an average of 1.44 pounds have, in effect, multiplied the usefulness of the raw fuel more than fourfold. Few capital investments appreciate at faster rates. A dollar deposited in a savings bank at $3\frac{1}{2}$-percent compound interest in 1902 would have increased to 3.45 dollars by 1938. A ton of coal saved underground for future recovery in 1902 would have appreciated by 1938 to an equivalent of 4.44 tons in terms of power derivable from it.

Conservation in use and conservation in extraction, therefore, go hand in hand. The past gains of fuel technology, foreshadowing further gains in the future, reinforce the case for preventing waste in mining.

PART FOUR—SECTION I

THE CONSERVATION MOVEMENT WITH SPECIAL REFERENCE TO THE MINERAL FUELS[1]

By John W. Frey[2]

In the United States the genesis of the concept of conservation of natural resources is directly related to the limitation of frontier expansion. As long as there was virgin land for farming available at little more than the asking, virgin forests bordering the areas devoured by fires or the rapacious mills, new streams and lakes to explore and fish, marshes and duck ponds alive with game, there was no practical consideration given to the problem of conservation. With respect to natural resources, the pioneer was essentially an individualist; he considered it his inalienable right to take what he found, when, how, and in the quantity he desired. The policy of the Government up to the period of the Civil War generally reflected the pioneer's attitude, and the disposal of land, was considered primarily as a source of revenue and as a means of encouraging settlement. As the country became more settled and the use of our natural resources more intensified, the people were faced with new facts and were forced to revise their concepts to fit these new facts.

The apparently inexhaustible abundance of wildlife encountered by the early settlers and colonists occasioned little if any thought for its future welfare or conservation. However, its rapid depletion in more settled regions affected the welfare of the settlements and resulted in ordinances restricting hunting, especially during the period of reproduction. In Massachusetts, deer were protected by a closed season as early as 1693. By the end of the colonial period, 12 colonies had enacted game laws, but from then until 1850 only 7 more States passed such enactments. From the sequence of events during the 1870's it appears that the depletion of wildlife had gone on apace and that the laws were inadequate to cope with the situation.[3] This inference is supported by the fact that a number of game and fish associations were organized to improve conditions affecting hunting and fishing, and by the establishment of State fish commissions in 4 New England States (1865–1867), and a Federal Fish Commission in 1871 to look into the apparent diminution in the supply of fish and to propose remedial measures. Since this first move by the Federal Government, continuing attention has been given to the problem of fish conservation, although progress has been slow and at times suspended. Sportsmen and biologists have kept the idea of game and fish conservation alive, and much has been accomplished toward offsetting the causes of depletion. Since 1900 the Federal Government has been a constructive factor, especially through the development of the Biological Survey, the Forest Service, the Bureau of Fisheries, the Park Service, the Bureau of Lighthouses, and through the negotiation of treaties.

Deforestation and the destruction of the natural habitat of wildlife have been concomitants, but the decimation of wild animals was more immediately felt by the early settlers than the reduction of forest areas. As virtually all of the country east of the Mississippi River was forest-covered, the pioneers had to clear land for farms. While the English Government considered that the forests of the Colonies were worth considerable attention and, in 1698, appointed a "Surveyor General of the Woods," whose official duty presumably was to prevent forest destruction, and while William Penn ordered that 1 acre out of every 5 should be left in woods, the colonists generally regarded the woods as a hindrance to agricultural development and the total supply inexhaustible in any event.[4]

The importance of wood for the construction of ships was recognized early in our history, as is indicated by the fact that Congress, in 1799, appropriated $200,000 for the purchase of a forest reserve containing ship timber and directed officials, in 1827, to grow live oaks for ships. However, as far as the Government's restraining the denudation or adopting a land policy to guide the utilization of the forest land,[5] nothing apparently was done until the closing years of the nineteenth century, when the problem was effectively brought to the attention of the Congress by scientists. Consciousness of the importance of forests appeared with the rapid industrial development of the country incident to the multitudinous use of iron and steel and the release of energy through coal-steam equipment.

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[1] This summary has been prepared almost entirely from original sources, in several cases unpublished manuscripts. As about 200 items were consulted it was considered more desirable to facilitate the reading than to make so many citations. I wish to thank members of the Geological Survey, the Bureau of Mines, and the Bureau of Reclamation for their assistance in supplying material and Dr. J. R. Whitaker, Department of Geography, University of Wisconsin, for his constructive criticism of the first draft.—J. W. F.

[2] Associate Director, Petroleum Conservation Division, Office of the Secretary of the Interior.

[3] The principal weakness of the laws seems to have been the lack of provision for adequate administrative personnel.

[4] According to J. P. Kinney (*Forest Legislation in America Prior to March 4, 1789*), the first legislation having as an object the conservation of the supply of timber appears to have been an order of the Plymouth Court, March 29, 1626, forbidding the transportation of any timber from the colony without the approval of the governor and council. The preamble of this order recites the inconveniences likely to arise from lack of timber. The inadequate transportation facilities of that period made a local supply of timber imperative for local needs. The same author cites legislation to prevent forest waste through indiscreet firing of woods as early as 1633.

That the colonists had their own ideas about exploiting the forests and resented the Government policy of setting up reserves is indicated by their disregard for Government orders which culminated in an act passed in 1708 imposing a penalty of 100 pounds for every white pine or mast tree 24 inches or more in diameter, not private property, cut or destroyed without royal license.

Until the middle of the nineteenth century, the chief source of fuel was the forest; coal was of minor importance. Up to 1845 the grand total of coal extracted in the United States is estimated at 27,700,000 tons, in 1850 the production was 7,000,000 tons, but in 1875 it had risen to 52,000,000 tons, and by 1900 to 270,000,000 tons.[6] The use of coal and iron, which were in abundance, made it possible to reduce the forests rapidly for farm occupancy and to haul agricultural products great distances to markets. As the forests were felled, farms and villages grew from them—this almost literally, as wood was generally employed for all types of construction, railway ties, bridges, houses, barns, stores, elevators, factories, fences, telephone and telegraph poles, boats, barges, agricultural machinery, wagons, freight cars, and so on. Along with the useful employment of wood went large wastes and losses, such as forest fires, abandoned small timber and slashings, the opening of steep slopes to erosion, and the creation of waste products in milling.

American scientists traveling and studying in Europe were imbued with ideas of better forest management and became militantly indignant over the wasteful methods they knew in this country. These men recognized that the reckless exploitation of our forests would lead to shortage and want. Scientific forestry, incidentally, had developed most extensively in a country that had to husband its resources, a country which was not then going through the colonizing process, and which, in consequence, developed economic principles at variance with the laissez-faire policy which our country had inherited from its colonizing English forebears. As early as 1841 the realism of the training for government service in Germany is reflected in the publications of the economist, Frederich List, who stated that the ability to develop productive power in the future was more important than present productive capacity.

During approximately the same period that American scientists were being influenced by European realism, American economists were gradually changing from abstract and deductive economics to the consideration of more immediate and concrete problems. The idea was taking hold that among the proper functions of government was that of guarding certain permanent interests of the Nation.

The original movement which resulted in the present national forest policy appears to trace back to a paper read by Franklin B. Hough before the American Association for the Advancement of Science, in 1873, in which some of the evil effects of deforestation and some corrective measures were pointed out, and which concluded with a significant recommendation—

> I would venture to suggest that this Association might properly take measures for bringing to the notice of our several State governments and Congress with respect to the Territories, the subject of protection to forests, and their cultivation, regulation, and encouragement; and that it appoint a special committee to memorialize these several legislative bodies upon this subject, and to urge its importance.

The memorial suggested was sent to Congress in 1874. In 1876 the first real forest work of the Federal Government got under way with the appointment of a special agent by the Department of Agriculture to study general forest conditions in the United States. In 1881 a Division of Forestry in the Department of Agriculture was created, but for a long time its appropriation was too small for effective work beyond the giving of information and advice.

In 1891 Congress authorized the President to set aside forest reserves in order to protect the remaining timber on the public domain, but the necessary system of organization and management was not provided until 1897, when the reserves were placed under the administration of the Secretary of the Interior. Systematic surveys were made of many of the northwestern forests of the United States by the Geological Survey. Timber was classified, the quantities of the various types estimated, and maps and reports prepared and published. Thus, a systematic factual survey of the western forests was begun.

The small beginning made in the Department of Agriculture in 1881 was the nucleus of the Bureau of Forestry which came into existence in 1891 and expanded into the Forest Service in 1905, when the Federal forest reserves were placed under its management.[7] Congressional action in 1891 was doubtless due to the recommendation in 1890 by the American Association for the Advancement of Science that a commission of competent men be employed to investigate the necessity of preserving certain parts of the public domain as requisite for the maintenance of favorable water conditions.[8] The expansion in 1905 of the activity of the Federal Government in forestry should be considered in the light of other conservation activities in the administration of Theodore Roosevelt, around whom raged a political storm of conservation and anticonservation controversy.

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[5] For the history of the public lands down to 1880 see *The Public Domain—Its History with Statistics*, Public Land Commission, Washington, D. C., 1880.

[6] Prior to 1864 coal lands were not specifically noted for reservation or sale, but were disposed of as other lands under allotment. *Ibid.*, p. 292.

[7] Since 1905 the area of the national forest system has more than doubled.

A discussion of greater length than is possible here should trace the changes in land laws applicable to the public domain and the cooperation of the Federal Government in relation to private and State forest lands. As the land laws, however, were, in general, the result of thought concerning the public domain rather than the cause of the thought, no attempt will be made here to deal with them as a unit.

The Homestead Law of 1862 is the clue to the character of the last phase of the occupation of the public domain by farmers. This law was based upon the idea that the frontiersman who made a farm performed a public service and, consequently, that the Government was justified in giving lands to citizens willing to cultivate them. That the intent of the law was better than the practice is indicated by the fact that entrymen often had no intention of settling on the land but made the minimum cash payment and sold immediately to exploiters. Before the close of the century, farmers had difficulty in finding suitable farms. A very high percentage of the better land of the humid region had been taken up, and the easily irrigated sections of the semiarid and arid regions had been developed, but there was still much promise in these drier areas if the aridity could be overcome.

The reclamation act of 1902, under the authority of which the Government started the construction of irrigation projects, appears to have grown from a germ in the mind of a dreamer who, as an explorer soon after the close of the Civil War, surveyed in the area west of the 100th meridian. Major Powell, who had, largely at his own expense, traveled in Colorado in the late 1860's, secured Federal financial aid in 1870, 1871, and 1872 to explore the Green and Colorado rivers. When he completed his field work on the Colorado River, he succeeded in getting further appropriations for 5 years for a geographical and geological survey of the Rocky Mountain region. This experience in the West was not all mapping. Just how his dream began is unknown, but he came from that area with what one may now call a "broad vision" of the reclamation of the "Great American Desert." In 1878 he published a report on the "Lands of the Arid Region of the United States." In the letter of transmittal he said:

> After setting forth the general facts relating to the conditions under which these lands must be utilized, I have taken the liberty to suggest a system for their disposal which I believe would be adapted to the wants of the country.

In the preface he put his finger on the problem, stating—

> To a great extent, the redemption of all these lands will require extensive and comprehensive plans, for the execution of which aggregate capital a corporation will be necessary. Here, individual farmers, being poor men, cannot undertake the task. For its accomplishment a wise provision, embodying carefully considered legislation is necessary * * * to the Arid Region of the west thousands of persons are annually repairing, and the questions relating to the utilization of these lands are of present importance.

It is not necessary to go into the detail of three other exploratory surveys of the west, the Wheeler survey, the King survey,[9] and the Hayden survey, all of which took place approximately simultaneously with that of Powell. Conflict of interest led to a controversy in Congress and to the solution, the establishment of the United States Geological Survey in 1879. King, the first Director of the Geological Survey, had published maps of country along the 40th parallel that placed the lands of northern Nevada in natural categories—mineral lands, irrigable lands, forest lands—and had recommended that these use characteristics be made the basis of their disposal. As the second Director of the Geological Survey, Powell was interested not only in topographic mapping and land classification but also in the reclamation of arid lands. In 1888 he succeeded in getting action in Congress authorizing an irrigation survey which did the first Federal work on the measurement of stream flow and on the mapping of lands best suited to irrigation, indicating possible reservoir and canal sites. It is not possible to consider in detail the many vicissitudes encountered at that time. The work started by Powell[10] was continued by Newell, who developed the water resources work of the Geological Survey. Since 1894 there has been continuous activity in stream gaging.

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[8] The purchase of additional lands valuable for the protection of the headwaters of navigable streams or for timber production, and their reorganization as national forests were authorized by the act of March 1, 1911 (Weeks law), amended by the act of June 7, 1924 (Clarke-McNary Law).

[9] The King survey advanced sound ideas about the classification of the public lands and their disposition in accord with their character that were far in advance of the time.

[10] The survey, under his direction, brought about in the middle 1880's the reservation of valuable reservoir and dam sites in the Western States which it was foreseen would be requisite for conservation of water and irrigation. Although Congress defeated this far-sighted movement and restored the lands to acquisition, only to have to supply public funds a generation or two later to buy them back, the public debates attending these activities did much to educate the public mind about the vital part that water played in the western economy, and thus helped lay the foundations for the later Reclamation Act and the water conservation movement.

The first stream gaging work done under the authorization of the Irrigation Survey was discontinued by Congress in 1890, as a result of the opposition in the West to the withdrawal of irrigable land. At this time, those westerners interested in irrigation believed that the Federal Government should turn over land of the public domain suitable for irrigation to the States and Territories. Within 3 years, there had been some change of heart, for the International Irrigation Congress of 1893 suggested that a National Commission be created to study the course to be followed. There must have been no general appreciation of the fact that the areas which could be irrigated were but a small part of the total arid region, for Powell was hissed when he stated that the water supply was sufficient for only a small part of the available land, although he was wholly right and his critics wholly wrong.

Congress, in 1894, granted to each State in the arid region public land not to exceed one million acres to be irrigated by any means the State might choose; but these grants generally were of no value, as the large systems required were beyond the financial ability of the States. That there was no faith that the outcome of such grants would be satisfactory is indicated by the resolution of the Irrigation Congress of 1894 advocating a national irrigation commission. The attitude of the westerners appears to have shifted rapidly following this pivotal period as a result of a series of drought years and the drying up of private funds following the panic of 1893. Irrigation was wanted, and since it was virtually impossible to get eastern capital interested, the appeal was made for Federal funds. By 1899 it became apparent to the leaders in the irrigation movement that a more permanent form of publicity was needed, and accordingly they formed the National Irrigation Association to promote support for Federal financing of irrigation. A Federal aid-for-irrigation plank was included in the platforms of the three leading political parties in the campaign of 1900.

At the National Irrigation Congress of 1900, two points of view were expressed, the first opposed putting the Federal Government into the irrigation business, the other held that the Federal Government as the proprietor of large areas of public lands was justified in preparing such lands for use and settlement. That the second point of view was more acceptable to those in the Government interested in irrigation is indicated in the Annual Report of the Secretary of the Interior for 1901, clearly inspired by Newell, which stated:

> The whole trend of enlightened public sentiment is in favor of an expansion of industries and commerce internally through wise action by the national government rather than attempting to get rid of the duties and opportunities of ownership by giving away this valuable property * * * Where there are unappropriated waters flowing to waste which can be brought within reach of public land, it is possible to make provisions such that the government can be reimbursed for its expenditure. The lands to be benefited by such works should be reserved for homestead entry only in small tracts, each being subject to the payment, before the title is finally passed, of a sum equivalent to the cost of storing or conserving the water. * * *

The western Congressmen, by acting as a bloc under the leadership of Newlands of Nevada, pushed the reclamation bill through Congress, whereupon the use of water resources and the reclamation of arid lands became a national policy. Thus, the 20 year campaign of the Geological Survey and its leaders finally educated the public and the Congress to the point where the Reclamation Service was created in 1902 out of the Hydrographic Branch of the Survey. It was administered by the Survey until 1905, when upon the recommendation of the Director it was established as a separate bureau. Conservation of western public land and waters was thus at last effectively launched as a Federal enterprise.

Before dropping this phase of the subject, attention should be drawn to several important changes in economic life that helped concentrate attention on reclamation. There was a great industrial growth in the country following 1880 and, with it, a demand for power and water. Steam power plants demanded large quantities of condensing water, industries required water for processing, urban populations demanded an abundance of pure water for home uses, and electric transmission had made water power available at a distance from the dam site.

Following the reclamation act, Theodore Roosevelt's interest in conservation was played on from many directions, and it is not clear which of the forces was the most significant in bringing about his appointment of the Inland Waterways Commission in 1907. Agriculturists were interested not only in irrigation of arid lands and the drainage of marshes but also in the prevention of soil losses through erosion. Forest-minded persons emphasized the importance of forest reserves in the maintenance of slow run-off, in the reduction of erosion and flood prevention through watershed protection, and in the maintenance of stream flow for navigation and water power. Sportsmen and biologists emphasized the value of forests as sanctuaries for wildlife. Chicago was completing a "sanitary ditch" to divert the pollution from Lake Michigan, their water supply, into the Illinois River. St. Louis was building a modern filtration plant to take the dirt from Mississippi River water. New York was turning toward the Catskills for a larger water supply. The Panama Canal was under construction. A dam at Keokuk was to change the character of the Mississippi River. Cities in the Ohio Valley were urging Ohio River improvement for better transportation and flood control. Kansas City with a real objective of flood control was urging Missouri River improvement for navigation. Levees along the lower Mississippi River had been strengthened. There was also a great deal of talk concerning the revival of the steamboat trade, which carried the suggestion that it might offer effective competition to the railways which were decidedly under fire for many of their abuses.

Consequently, it was not peculiar that Roosevelt in his speech at Memphis, October 4, 1907, during his cruise down the Mississippi, should have said—

> Citizens of all portions of the country are coming to realize that, however important the improvement of navigation may be, it is only one of the many ends to be kept in view. The demand for navigation is hardly more pressing than the demands for reclaiming lands by irrigation in the arid regions, and by drainage in the humid lowlands, or for utilizing the waterpower now running to waste or for purifying the water so as to reduce or remove the tax of soil waste, to promote manufacture and safeguard life.

He had asked the waterway committee to take account of the orderly development and conservation, not alone of waters, but also of the soil, the forests, the mines, and all other natural resources.

The committee suggested that, as the question of conservation concerned not only the nation but every state, a conference of governors should be called. This was done, and the meeting convened in Washington in May 1908. This meeting resulted in a declaration of principle which included, among other things, assertions that the conservation of natural resources is a subject of transcendent importance; that erosion and soil wash should cease; that there should be reclamation by irrigation and drainage; that water should be conserved to promote navigation, irrigation, and water power; that forests should be preserved and perpetuated; that Congress should adopt a wise, active, and thorough waterway policy; and that there should be enactment of laws for the prevention of waste in the mining and extraction of coal, oil, and gas and for the protection of human life in mines.

The conference of governors was followed by the President's appointment of the National Conservation Commission, which, at its first meeting in June 1908, decided that an inventory of our natural resources was necessary and asked the Federal scientific bureaus to do the work. The reports were made in December 1908 to the Commission and the governors, who transmitted a report to the President, who, in turn, transmitted it in a message to Congress in January 1909, with a recommendation for a $50,000 appropriation to continue the work of the committee.

The report in three volumes totalling over 1,800 pages was developed around four broad topics; water, forests, lands, and minerals. The relationship of the first three of these had been close for a number of years, as has been heretofore suggested; the introduction of minerals brought in a comparatively new subject. The President's recommendation on water urged the development of inland waterway improvement

> extending to all the uses of the waters and benefits to be derived from their control, including navigation, the development of power, the extension of irrigation, the drainage of swamp and overflow lands, the prevention of soil wash, and the purification of streams for water supply.

Under the heading "Forests" he urged

> both protection and more rapid development of the national forests

and "commended" to Congress the facts as to the

> relation between forests and stream flow in bearing upon the importance of the forest lands in national ownership.

Relative to "lands," he praised the Department of Agriculture for its work on crop betterment and the enemies of plant life and recommended continued liberal support.

> The remaining public lands should be classified and the arable lands disposed of to home makers. In their interest the timber and stone act and commutation clause should be repealed and the desert-land law modified * * *.

He recommended that the use of public grazing land be regulated to improve and conserve their value, that surface rights on public lands be separated from forests and mineral rights.

> The coal, oil, gas, and phosphate rights still remaining with the government should be withdrawn from entry and leased under conditions favorable for economic development.

Under "Minerals" he stated,

> It is of the utmost importance that a bureau of mines be established in accordance with the pending bill to reduce the loss of life in mines and the waste of mineral resources and to investigate the methods, and substitutes for prolonging the duration of our mineral supply.

These were the spectacular general movements designed to educate the public in the value of conservation. They represented the emergence as a national issue of ideas long advocated by the small groups of scientists, generally in the Government services, who deplored the wastes in and the inept laws that controlled the disposition of the Nation's mineral, forest, and water resources.

The Reclamation Act had been passed, the Forest Service had been created, and thus practical progress had been made in conservational directions before the National Conservation Commission met.

Activities thus far had been directed chiefly to the saner management by the Government of the more obvious visible resources, water and timber, somewhat to the neglect of the mineral resources. Meanwhile, the Geological Survey, which had participated actively in the movements for conservation of forests and water, had begun to call attention to the situation in regard to minerals. Before 1908, on its recommendation, oil and coal lands had been withdrawn from entry, for the purpose of classifying them in accordance with their values and for the further purpose of stimulating the enactment of wiser laws for their disposition.

As this discussion is intended primarily to trace the beginnings and evolution of thought on conservation by the Federal Government and is only incidentally a record of accomplishments, only a few consequences of the 1909 activities will be mentioned. The National Conservation Commission attracted wide attention to the problem, but the idea of conservation was not acceptable to all of the interests that had a finger in the pie. Congress was suspicious, probably because a high percentage of its Members were not "posted" on the subject, and feared that new policies in conservation might upset political and business interests of long standing. There were also Members of Congress who were not in sympathy with Roosevelt's "big stick" policy or were for other reasons unfriendly. As a result, Congress killed the possibilities of continuing the work of the Conservation Commission by refusing the recommended appropriation and by prohibiting the Federal bureaus from providing information to any commission appointed by the President. While the President had no legal authority to establish methods for the disposition of timber or mineral lands or water rights, he was able to withdraw public land from entry and to continue with surveys. From this ferment there developed, within a few years, the so-called Separation Acts which recognized that farming and grazing activities were not hampered by the lack of title to minerals. The purchase of additional lands valuable for the protection of headwaters of navigable streams was authorized by Congress in 1911. The following year an act directed that national forest lands be classified to determine those chiefly valuable for agriculture, which resulted in practically all agricultural lands within the national forests becoming homesteads. It was not until the passage of the Clarke-McNary Act of 1924 that the establishment of national forests by purchase for timber production was authorized.

Since the course of this summary is particularly directed toward the development of the conservation idea with respect to coal, oil, and gas, interesting and significant though developments in the conservation of water, forests, and agricultural lands have been, it is, nevertheless, impractical to follow them further.

There are parallels between many of the problems of forest, water, and soil conservation and those of mineral conservation. Since, however, the percentages of oil, gas, and coal resources in the public domain are comparatively small, mineral conservation problems fall much more in the field of regulation than in that of management of something to which the Federal Government has title. This has made it difficult to advance independently and free from conflict with state rights and with the peculiarities of the legal interpretation of what constitutes property, developed prior to any general recognition of the national interest in mineral resources.

Although a general coal land act, passed in 1873, provided for the sale of Federal coal lands at not less than $10 an acre for those more than 15 miles from a finished railway, 160 acres to the individual and not more than 640 acres to an association, nevertheless, a large percentage of the coal land of the public domain had passed into private hands with agricultural land before the end of the last century. This transfer of coal land with agricultural land was by no means always fraudulent, for the designation that the land was not coal land was determined by the farmer's say-so, and he did not, as a rule, have any way of knowing what was under the land. This situation was irksome to the Geological Survey, but there was nothing they could do about it until a request came from the President and the Senate in 1906 as to the extent, location, and value of coal on public lands. The Annual Report of the Geological Survey for the fiscal year ending in 1906 stated:

> It has been demonstrated that many millions of dollars can be saved to the Government by a geological examination of its coal lands at a cost of less than 1 percent of the amount saved.

Therefore, in 1906, the work was started to determine the quantity, quality, and value of coal lands remaining in the possession of the Government. It was believed that obtaining coal prices for coal lands would discourage purchase by speculators so that the lands would not be sold until needed, and in that way, the possibility of monopoly would be reduced without promoting overproduction and wasteful competition. In 1909 a regulation was approved basing the selling price of coal lands on the tonnage and quality of the coal.[11]

The coal work of the Survey led to the consideration of other problems of coal mining. That of safety was precipitated by an appalling series of mine disasters which resulted in the death of 1,148 men, in 1907, chiefly from explosions of coal dust. Up to 1897 miners had been paid on the amount of lump coal produced, but with a change in the basis of payment to run-of-mine, there was a premium on shooting down coal in the cheapest and easiest manner. This resulted in shooting off the solid and an immediate increase in the number of explosions and fatalities. The safety work started in the Geological Survey and transferred to the Bureau of Mines with its establishment in 1910 has continued and has resulted in human conservation of inestimable value. Although the Bureau recognized the desirability of mining laws designed to secure safety and efficiency and made a study of such possibilities over a long period, nevertheless, its work has been almost entirely fact-finding and educational (not only what to do but how to do it), in cooperation with the States and the industry.

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[11] Some of the best coal lands were classified at $300 to $400 per acre.

The revision of the organic law of the Bureau of Mines in 1913, among other things, authorized the Bureau to—

> conduct inquiries and scientific and technologic investigations concerning mining, and the preparation, treatment, and utilization of mineral substances with a view to improving health conditions and increasing safety, efficiency, economic development, and conserving resources through the prevention of waste. * * *

This authorization must have been envisaged by Dr. Holmes, the first Director of the Bureau of Mines, 10 years earlier when he was preparing the exhibition on coal testing for the Geological Survey at the Louisiana Purchase Exposition in St. Louis, where, for the first time, any considerable number of the public received instructions on the difference in coals and the problems of combustion. It is not especially to the point here to go into a discussion of the cooperation of the Bureau of Mines with manufacturers in the development of so-called permissive mine equipment such as lamps, cars, electric motors, electric switches, explosives, etc., nor of the cooperation with the States in an effort to secure uniform safety codes. It must be recognized, however, that these efforts have been toward conservation, although without direct application to the prevention of waste of coal per se.

Aside from the regulations applicable to coal mining on public lands, which will be commented on later, neither the Federal Government nor any State has laws requiring the elimination or reduction of waste in mining, yet education in the importance of such procedure has been a concern of the Bureau of Mines almost from its inception. Coal mining is now concentrated on the rich and accessible deposits, and these are being rapidly depleted. The significance of using the best and most convenient coal is obscured by the optimistic estimates of reserves. While the coal commission in 1923 reported that progress had been made in the bituminous coal industry over the practice of earlier years and the average percentage of loss declined from something like 64 percent in 1850 to something like 35 percent in 1923, it is doubtful whether, with the more adverse economic conditions that set in about the time of the report, the losses on an average have remained at the lower figure; some mining operations are better, and others are worse.

During the World War the educational work of the Government directed toward economy in use, plus the inherent characteristic of industry to reduce costs, started a movement in fuel technology that has resulted in a marked improvement in efficiency in use, as is indicated by the fact that a given unit of electric power is now produced by public utilities with less than half as much coal as was required in 1917. Conservation in use generally results in lower costs, but conservation in the mining operation almost certainly results in higher costs. Even the smallest increase in costs becomes a formidable obstacle to conservation under the destructive competition characteristic of the bituminous-coal industry. As stated by Rice, Fieldner & Tryon, of the Bureau of Mines, at the 1936 World Power Conference:

> * * * the individual operator, acting alone, can hardly avoid the use of wasteful methods. To assume additional expense, unless it is also borne by his competitors, would soon put him out of business. At best, his own direct incentive to increase recovery goes no further than the point that would yield maximum profit in the long run. Under the cut-throat competition of the last decade, he has been forced to neglect even his own long-run interest in the necessity of reducing his immediate cash cost. For much the same reasons, it is impossible for the individual State to act alone. In the division of labor between the State and the Federal Government, the States have the constitutional powers to regulate waste, but under the present conditions no single State can well take action. * * * The first indispensable step in reducing the wastes of mining is to aid the industry to establish itself on a stable and profitable basis.

The agitation for a change in the law governing the disposition of the coal on the public domain finally led to the passage of the first leasing act—the Alaska coal-leasing act of 1914. The regulations under that act set up a few conditions intended to reduce the waste in mining. The agitation for the disposition of mineral resources by lease rather than by sale continued and finally resulted in the general leasing act of 1920, which replaced earlier legislation providing for the sale of certain publicly owned nonmetalliferous mineral lands and provides for their development under lease. These leases are subject to regulations of the Department of the Interior on several counts including the "prevention of undue waste" and the prohibition against premature abandonment.

Aside from coal mining on the public domain, conservation in that industry has been entirely a matter of private initiative and up to the close of the period covered by this summary, practically no laws, except those relating to safety, had been directed to the elimination of waste or losses. The oil and gas industries, probably by reason of the physical conditions of occurrence and production, and the legal concept of property (i. e., reduction to ownership by capture as against ownership in place as in the case of coal) have with a succession of economic impacts attempted various solutions directed toward stabilization and conservation.

Today, the conservation of oil and gas are in most areas and by most engineers considered as inextricably related, but this point of view, it must be admitted, is comparatively recent, as the function of gas in the production of oil was appreciated by only a limited few as recently as 1920. Something better than 55 percent of the natural gas produced is incidental to the production of oil, and most of the gas wells yield some natural gasoline. While this production relationship is significant, the physical relationship in the natural reservoir and the effect of gas upon petroleum production is a key fact in conservation.

The report of the National Conservation Commission (1909) divides waste of natural gas into three classes: (1) waste incident to the discovery of a natural-gas field, (2) waste in oil production, (3) waste in consumption. Nothing is said about the effect of the waste of gas upon the oil remaining in the reservoir. The report points out that the oil well driller in the early days of the industry could not obtain a prompt and profitable market for natural gas and, consequently, regarded it as a nuisance and menace. The greater the volume, the greater the menace.

> It developed a hostility toward natural gas on the part of the oil well driller, which has increased rather than diminished up to the present time.

After commenting that only half of the gas produced goes to any useful purpose the report states that the remedy by legislation—

> has been extremely effective in Indiana, Ohio, and Pennsylvania. Only a part of the credit for stopping natural-gas waste is due to legislation, much credit being due to the natural-gas companies themselves for taking the initiative in this reform. * * *

Indiana was the leader in legislation on gas conservation. In 1893 it passed a law prohibiting the flow of gas or oil from a gas or oil well into the open air. This act was a direct recognition by that State of the necessity of gas conservation, as is clearly reflected in the claim of the plaintiff in Indiana vs. Ohio Oil Co. before the United States Supreme Court. After describing the gas producing area, the claim was made that—

> the fuel supplied by natural gas thus obtained is the cheapest and best known to civilization, and the value of the natural gas to the State and to its citizens is many millions of dollars; that since the discovery of said gas deposits in 1886 immense sums of money have come into the State and have been invested in large manufacturing interests, and other sums of money belonging to the people of the State of Indiana have been invested in similar enterprises causing a great increase in population, principally in the territory underlying which said gas is found. Many cities in and adjacent to the gas territory, including those named, are wholly dependent for fuel upon natural gas, and for that reason the people of the State of Indiana are interested in the protection of the natural-gas supply.

The plaintiff claimed that—

> if the gas supply is husbanded and protected it will last for many years and continue to furnish the various cities named with abundant fuel, and the population, wealth, and other material interests of the State will continue to be benefited and enhanced, and the comfort, happiness, and enjoyment of the people of the State greatly increased.

In the claims made there was recognition of the effect of waste upon the common supply, and the court in ruling said that the Indiana law—

> is a statute protecting private property and preventing it from being taken by one of the common owners without regard to the enjoyment of the others.

One of the most illuminating claims made, somewhat off the main argument, was to the effect that the field

> is greatly damaged by the destruction of "back pressure" which is necessary to protect the gas supply from the invasion of salt water.

Curiously, although the gas in question in this litigation was produced from oil wells, nothing was said about the effect of "back pressure" and its value in the production of oil. The separation of thought on oil and gas is, however, more clearly reflected in the decision of the supreme court of Indiana (1898), from which court the United States case had been referred. The Indiana court said substantially, we imported oil into Indiana a third of a century before oil was discovered in this State and we can do it again,

> but we cannot have the blessings of natural gas unless measures for the preservation thereof in this State are enforced against the lawless.

Except for the administration of the leasing act of 1920, the gas conservation activities of the Federal Government have been almost entirely confined to leadership toward better practices. The Bureau of Mines during the first 2 or 3 years was concerned primarily with coal, but in 1912 we find an engineer visiting the California oil fields with the object of investigating methods of preventing the waste of oil and natural gas from flowing wells and field work being done in Kansas and Oklahoma oil and gas fields (many of which were on Indian lands) to ascertain the conditions that led to the enormous gas waste in those States. Investigations were made of a cementing process as practiced in California for excluding water from oil wells. In Oklahoma it was demonstrated how oil and gas waste in drilling could be prevented by the use of "mud-laden water." The Bureau of Mines launched its program of waste prevention by the same general methods as in the case of coal; that is, fact-finding and education, industrial, and State cooperation.

Following the activities of several States in the early nineties in the prevention of gas waste, there was a long interval of stagnation, but in 1911 California enacted a law prohibiting the unnecessary wasting of natural gas into the atmosphere. Then, in 1915, a department of natural resources was authorized in that State to protect the natural resources of water, petroleum, and gas from damage, waste, and destruction. The same year, another law was approved designed to prevent damage to oil-bearing strata by the infiltration from water-bearing strata.[12] A review of the first few years' operations of the State oil and gas supervision shows that almost all of the work was toward the prevention of the flow from water sands to oil sands, the value of which had a great deal of natural appeal to water-conscious Californians. No strain was placed on the mandatory features of the California law as virtually all of the effort was expended in the education of oil men to an appreciation of the importance of using proper methods of casing and cementing. Although the California gas and oil law has been amended a number of times there has been no considerable departure from the principles of the original acts, unless one recognizes in the procedure aimed at the prevention of the unreasonable waste of gas into the air and the shutting out of oil from water sources something that could not have been envisaged in the first acts. In 1931 a well spacing law was enacted in California.

The production of more oil than the market could absorb with attendant price depression, a recurrent event with the discovery of large oil fields in Oklahoma, principally Healdton and Cushing, led to the development of the proration idea. At first, the Oklahoma Corporation Commission tried to curb the effect upon price by prohibiting the purchase from certain pools at less than a fixed price. In 1915 a proration law was passed, but before it was tested the World War demand for oil set in with a rapid rise in the price, so the law was a dead letter throughout the war period and several years thereafter.

The war did a great deal to make the United States oil conscious, and the stimulation of production left the country with many problems. Considerable emphasis during our participation in the war was given to conservation in use. The fact that the demand exceeded the supply forced the economists to give their attention for a period to the break-down of the doctrine of laissez-faire, since the law of supply and demand was no longer operating in the national interest. The Lever Act in 1917 for the conservation of food and fuel was the result. Oil from January 1918 was under the oil division of the Fuel Administration. The oil, to all intents and purposes, was pooled and distributed regardless of ownership. For practical purposes the stored oil was the property of the Government, to be disposed of as might best meet the demand of the time. Considerable of the oil was allocated. All petroleum products were considered fuel and were subject to the same control in relation to practices and profits as food (the act had conferred authority for price-fixing of coal). The practice of refineries throughout the country of bidding up the price of crude oil was not viewed by the Government with approval, and in May 1918 the industry was advised that there was no justification for any further advances and that the Government expected the industry to cooperate in maintaining the then existing prices as maximum. Unrestricted competition was not considered to be in the national interest. The plan worked out for the stabilization of prices and the maintenance of an uninterrupted flow of crude oil included tacit or implied voluntary agreements restricting prices for refined products. The overseas demand for gasoline was so great by August 1918 that a request was made for gasolineless Sundays for pleasure purposes (five in September and two in October) in the area east of the Mississippi River.

For several years following the World War there was a strong demand for petroleum and, consequently, a marked stimulation in exploration. Doubts were expressed in many quarters as to the ability of the United States to meet its requirements, and the development of foreign deposits, especially Mexico and Venezuela, were looked on with favor. In 1920 the mineral leasing act put public oil lands on an entirely new basis for conserving oil and gas. In 1930 the Secretary of the Interior was authorized to enter agreements for unit development of the oil pools when determined to be necessary or advisable in the public interest. The regulations applicable to drilling and production methods on public lands were generally aimed toward conservation; that is, efficient production.

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[12] California was the leader in administration of this type of law; however, statutes attempting to protect strata were passed in Indiana (1893), Kansas (1891), Kentucky (1893), Ohio (1893), Pennsylvania (1881), prior to the California act; subsequently Tennessee (1917), Texas (1931), West Virginia (1931), and Wyoming (1920), passed laws for the same general purpose.

The experience of the Nation in the World War and the rapid development of motorized war devices, aviation especially, seem to have refocused attention on the conservation of petroleum. It is not impossible that the malodorous Teapot Dome affair may have prevented a drift of the public attention away from oil. By 1924 the results of "wild catting" were being felt through increased production, but the importance of continued discovery was recognized, even though the industry was faced with the enigma of how to preserve values in the face of growing reserves. In December 1924 President Coolidge appointed the Federal Oil Conservation Board to study the responsibility of the Government in the conservation of oil. This organization rapidly developed into an instrument for cooperation with the industry. Government bureaus went into the problem of present and future supply, questionnaires were sent to the industry, and early in 1926 two hearings were held by the Board.

One of the most striking things about the addresses at the hearings was the conflict of definitions of the word "conservation"; to many "conservation" meant hoarding. This concept is well illustrated in the speech (1926) of a man who within a very few years became a national figure in oil conservation. He said:

> I am not one of those who believe that there is any necessity for conservation, because I believe that there is a sufficient supply of oil to meet the demand for internal combustion fuel and lubrication for centuries to come, probably as long as our civilization and its necessities for petroleum shall exist. Having heard so much talk of conservation, naturally, I have considered how conservation might be effected, if and when necessary, and I could not avoid the conclusion that conservation must take the form of restricted production and restricted consumption. To me such restriction seems possible only through either Government ownership or monopolistic control.

To this man, in 1926, overproduction and cheap gasoline were synonymous and desirable, and restricted production would be the end of cheap oil, cheap gasoline, and the joy of living.

An independent producer, following the speaker just quoted, said:

> In the past 3 or 4 years it has been the discovery of a number of prolific pools at about the same time and the dumping into this country of a flood of oil from Mexico, duty free, that has upset crude prices and brought about wasteful practices. If it had not been for these happenings, the chances are we would not be here today. And these conditions can be and will be repeated unless the Government takes a little hand in the oil business.

At the second (May 27, 1926) hearing, the speaker representing most of the large oil companies "soft-pedaled" the idea of Federal conservation and at least strongly implied a doubt of State or Federal authority to conserve oil in the ground but hinted that there might be a solution by encouraging

> voluntary cooperation, to deal with the problem of production from an economic standpoint.

This advocate could only have been expressing the attitude of a fraction of the industry when he concluded that the conservation remedies were (1) scientific and (2) political. Paraphrasing what he said—scientific effort holds the promise of the future, and the Government can accomplish much in stimulating and leading research; competition will foster improvements, develop substitutes and promote efficiency; and political action, superficially attractive, is likely to fail, though something might be done by the removal of legal obstacles to intelligent cooperation. Only one man representing a large company raised his voice in opposition to this opinion. This man was ahead of his contemporaries in the industry in his recognition of certain principles of the function of gas as energy—principles which did not receive general consideration until several years later.

By the beginning of 1929 the Board reported:

> The complete organization of cooperative effort recommended by the Board in its first report has not been attained, but the keen and sustained attention given to the study of new methods, the many conferences held, the large number of working committees organized within the industry, and the cooperative spirit with which different units worked together are all indicative of a new appreciation of responsibility. The acceptance of the principles of conservation as a practical policy by the foremost executives of the larger oil companies is a hopeful sign of the times. The closer contacts both within the industry and between it and State and Federal officials also promise gradual betterment of economic conditions.

By 1929 the importance of gas in the conservation and economical production of oil had filtered into the consciousness of quite a considerable number of oil men. Although the Bureau of Mines had been doing research work along that line since about 1915 and had published a number of reports from 1920 onward, this work had not received general recognition by the industry. The hearings before the Board in 1926 indicate that only two or three at that meeting had any grasp of the subject.

In 1927 the American Petroleum Institute undertook to collect data relative to the function of gas in the production of oil. This work resulted in the accumulation of a great deal of data and a preliminary report late in 1927 to the directors of the institute, who, in accepting it, placed the institute on record as favoring the control and efficient utilization of natural gas occurring with oil. In 1928 more data were collected, and a cooperative agreement reached with the

Bureau of Mines led to a cooperative report in 1929, *The Function of Natural Gas in the Production of Oil*, a landmark in oil conservation literature.

In the early part of 1926 when the Conservation Board was holding hearings, the price of oil was satisfactory and the industry optimistic, or at least indifferent; but late in the same year, when the price of oil began to decline and conditions became uncomfortable, the proration law (Oklahoma) that had been relegated to the closet by the World War again came to life. At first, a group of Oklahoma producers entered into a voluntary curtailment agreement under a paid umpire. In 1927 the privately paid umpire was approved by the corporation commission, and his orders became the orders of the commission under the 1915 act. By 1930 the proration of the entire State had been thus promoted.

In Texas, the development of the Yates, Hendricks, and Winkler pools with their pressure on the market led to proration agitation, and a producer agreement for voluntary proration was reached in 1926. With no law, except for the conservation provisions in the Constitution to fall back on, the oil producers grasped at the idea of voluntary control, and this scheme spread to operators in other pools, with the result that the State Railroad Commission by the spring of 1931 was promulgating proration orders largely based on voluntary agreements.[13] Incidentally, the revised Civil Statutes of Texas, 1925, obligated the legislature to pass laws for the conservation of natural resources, and the 1928 statutes included oil and prohibited the waste in production, storage, or transportation of petroleum or natural gas. In 1931 the law prorating to market demand was passed.

No attempt will here be made to give a chronology of similar activities in other States following the general pattern of Oklahoma and Texas; it is sufficient to say that several other States did follow their example, although California by referendum in 1932 killed the proration law that had recently been passed and, consequently, the oil industry of that State returned to the earlier method of voluntary proration. The proration idea of 1915, applicable only to flush fields, had expanded and by 1932 had been extended to old as well as new fields.

To assist the States in their efforts at proration and for the guidance of the industry in its attempts at voluntary proration, the Federal Oil Conservation Board in 1930 organized the first volunteer committee on petroleum economics, which forecast the total United States demand[14] and suggested an allocation of production requirements as between the larger producing States. From time to time until the spring of 1933, other volunteer committees made similar reports, although all of them did not suggest allocations.

In 1929 the Secretary of the Interior, Dr. Wilbur, gave expression to the idea that the conservation of oil reserves would require the exercise of the States' police power and that the balancing of supply and demand would require the coordination of that power's exercise by common action of the individual States. This concept initiated the movement for State cooperation through an interstate compact, which movement at the end of Dr. Wilbur's term of office was part of a program sponsored by the governors of ten oil-producing States. The extension of that idea and further developments in oil conservation will be discussed further in a paper on the Connally law.

The growth of the conservation movement can not be plotted as a straight line curve, nor can it be considered as a peaceful development, for the entire course has been a battle ground with the forces at times about equally divided. Each step has required a period of adjustment and those who have lost opportunities through withdrawal of public domain or through regulations have, in almost every instance, put up a strenuous fight. The records of State and Federal courts are filled with the history of these fights. The noise set up in opposition to conservation has been about directly proportional to the stakes. In the petroleum industry, the problem of conservation is not only one of the gray zone of authority between the State and the Federal Governments, of the conflict of modern engineering knowledge with laws and precedents established during a period of little scientific knowledge concerning the nature of the underground reservoir, but also one of the cooperation of corporations of different levels of integration and financial power.

Conservation is inseparable from economics, and the profit motive has to a large extent determined which side of the battlefield individuals and corporations have chosen. Conservation and efficiency in operation are closely related subjects, and, as a rule, stabilized prices if at a sufficiently high level tend to encourage efficiency.

There are many in one or another branch (research, production, refining, transportation, or marketing) of the petroleum industry who are opposed to proration and insist that the law of supply and demand in a free market should govern the extension of reserves and production. Other oil men and economists insist that there is no law of supply and demand at either an extreme of supply or demand; that is to say, there is no regard for values and no meeting of the minds of buyers and sellers either when the market is glutted with too much of a product for the buyers to use or not enough of a product to meet the demand of the buyers. In the case of an excess demand, the sky is the limit unless substitutes are available, and with production far in excess of demand, the price reaction trend is strongly toward zero. Under laissez-faire theories and a free market, there is little or no opportunity for the individual to conserve petroleum in its natural reservoir even though he may personally desire to defer or extend the period of his profit, neither has he much choice in the conservation of his capital. Unless he is the sole controlling element in a pool, the utilization of the resource is beyond his direction. The best possible way of wasting a petroleum pool is to parcel it out to competing operators, each one intent on getting all he can without any control. There is nothing to assure in such a situation that the free market and the law of supply and demand will automatically throw off adequate supplies of petroleum. There is no assurance that under competitive drilling each interested party is equal to protecting his ownership in the common pool against drainage by the person of superior financial ability.

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[13] The umpires were selected by the Commission but were paid by the companies on a per barrel basis.

[14] The demand was estimated for motor fuel which was converted to crude oil requirements.

Certain opponents of legislation that has been proposed for petroleum conservation as well as some legislation now existent have expressed the opinion that there is enough oil or substitutes to last for hundreds of years and that the danger of exhaustion is far outweighed by the probability of technologic advances that may make petroleum valueless. Perhaps this point of view is only a protective reaction to the alarmist type of conservation advocate or is based on opposition to those plans for regulatory legislation which may be considered impractical or dangerous. It is, of course, true that without regard for the increased cost of products, an enormous new capital change, and probably a complete geographical shift of the industry, oil derived from coal could meet domestic requirements of this country for hundreds of years, but those who argue against conservation legislation, or more specifically Federal control of the petroleum industry, pass slightly over the question of costs and rarely give consideration to the social consequences.

The history of the development of the conservation concept is evidence that the wise utilization of resources and not hoarding is fundamental. In the field of mineral fuels, the emphasis is not on how long these vital materials will last, but on producing, processing, and using them with as little waste as possible. That oil may be a substitute for natural gas or that coal may be a substitute for oil, even though at increased costs, is fortunate but no reasonable justification for the waste of oil and gas. Under conservation measures conceived for the common good, it is just as reasonable to anticipate that the competitive position of motor fuel and other petroleum products may for many years be favorable to oil, as to assume that these products will be produced from coal for less than from oil, particularly when present information on synthetic motor fuels shows that costs are now several times greater than for motor fuel produced from petroleum. The possibility, though not of the immediate future, of using coal for the manufacture of a liquid motor fuel should, if anything, point to the wisdom of curbing the losses and waste in that industry rather than to continued wastefulness.

The history of the development of the conservation concept shows that the public welfare and the methods of the operators are often at variance, not necessarily by reason of stupidity, greed, malicious indifference, or other malevolent traits of the operators, but by reason of customs, principles, and laws improperly coordinated to meet current economic and technologic conditions. The conservation movement has not gone forward in a vacuum. It is not a religion. It is not conceived in pure altruism. It is a practical problem forced upon a people by their recognition of the limitations of frontier expansion.

PART FOUR—SECTION II

THE CONNALLY ACT: BACKGROUND

By John W. Frey *

The act of February 22, 1935, generally known as the Connally Act, is directly traceable to the "meeting of the Governors" [1] of the principal oil-producing States with the Secretary of the Interior in Washington, on March 27, 1933. The Connally law prohibits the shipment of contraband oil in interstate or foreign commerce.[2] This law is designed to assist the oil-producing States in enforcing their conservation laws. In order to understand the position of the Federal and State Governments in this legislation and the experience thereunder, it is desirable to trace the history of certain economic features of the oil industry and of governmental activities relating to oil during the period of chaos which was incident to the development of high potentials in Oklahoma and Texas during the years immediately following 1930. That year marked the discovery of the East Texas oil field, and this discovery of the largest oil field in the United States ushered in problems which have challenged many legal concepts of long standing.

Up to the period of the Great War, except for statutory settlement of a controversy between the State of Indiana [3] and an oil company over the waste of gas and a California law to prevent the waste of gas [4] and another to prevent the destruction of oil strata by the infiltration of water,[5] the field of oil and gas conservation received little legislative consideration. In 1915 the reduction in crude oil prices in the Midcontinent, caused by the heavy production of the Cushing field, resulted in a law in Oklahoma prohibiting the production of petroleum in such manner as to cause waste. The definition of waste included production in excess of transportation and marketing facilities.[6] With the World War demand, the Oklahoma law became a dead letter, until the initiation of a new period of heavy flush production in the Seminole field in 1926, with consequent reduced prices, revived the law. During the participation of the United States in the World War, supply-demand relationships were violently distorted as the demand was far in excess of supply, and only Federal intervention stopped the upward flight of price. After the war, the stimulation of discovery continued as more and more capital followed the drill into new areas, but the industry in general did not appear to be concerned. Representatives of almost all of the large companies at a hearing of the Federal Oil Conservation Board early in 1926 were sanguine as to the future as they had not had to face a big discovery for 10 years; like most oil men of the period they considered that they were doing a good job of voluntary conservation and did not want to see either the States or the Federal Government disturb their equanimity by the passage of laws, the provisions of which might be uncertain and untested. By the end of 1926 the lid had blown off, and the heavy production of new fields led to the discovery that supply-demand relationships could be upset by momentary superabundant supply as well as by superdemand. The period from 1926 to 1930 was marked by a series of new pool discoveries, each of which augmented the difficulty of absorbing production at which the producers considered a reasonable price. Had the demand for petroleum continued at the normal rate of increase, the problem would have been difficult of solution, but the enormous potential of East Texas became known early in 1931, at the same time that, as a result of the depression, the demand for petroleum was flattening out. The solution of the problem seemed no longer to be "laissez faire" but the enactment of legislation that would keep the structure of the industry from collapsing. The period from 1920 to 1932 was marked by the passage of conservation laws in most of the large oil-producing States, and proration of production to market demand took the spotlight of legislative and judicial attention. Two themes ran through most of that legislation, (1) to control production in order to prevent physical waste, and (2) to keep production at such level as to prevent demoralization of markets. Also, it was generally recognized that the known reserve can be measured in terms of a relatively small period (10 to 15 years), that continuity of supply is dependent upon success in

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[1] Except for the Governor of Kansas, all other State representations were delegated.

[2] Defined in the act as "petroleum which, or any constituent part of which, was produced, transported, or withdrawn from storage in excess of the amounts permitted to be produced, transported, or withdrawn from storage under the laws of a State or under any regulation or order prescribed thereunder by any board, commission, officer, or other duly authorized agency of such State, or any of the products of such petroleum."

[3] The law was passed in 1893 and the constitutionality affirmed by the United States Supreme Court in 1900.

[4] Stats. 1911.

[5] Stats. 1915.

[6] The constitutionality of this definition was not confirmed by the State Supreme Court until 1930, in *C. C. Julian Oil & Royalties Co. v. Copshaw.*

finding new oil pools, and that flush fields by their lower initial costs may, as a result of depressed prices, damage areas of settled production; all of which factors trace back to the maladjustments of unrestricted drilling and the so-called rule of capture.

Long before crude oil went to 10 cents a barrel in East Texas, operators in older fields had found their position imperiled. Not only were the oil men seeking the road to recovery, but States whose welfare is inextricably associated with the oil industry felt the effects of the flood of oil—attendant lower prices, reduced revenues, and a relief problem—and so were no less anxious than the companies to do something about it.

Various experiments were tried. The States were having a difficult time because a reduction in production by one only gave a better opportunity for the others. The necessity of coordination of State endeavors was recognized. There were also those who believed that the Federal Government has the authority to exercise all the functions which the State governments exercised in the regulation of production and advocated that the Federal Government exercise its authority. In the spring of 1929, a committee of the American Petroleum Institute placed before the Federal Oil Conservation Board a world-wide plan for the limitation of production to demand by voluntary agreements of American and foreign companies. The Attorney General expressed the opinion that such an agreement would not relieve the parties to such an agreement from the operation of the antitrust laws and that the board did not have the authority to grant immunity.

The then Secretary of the Interior, as chairman of the Board, did not consider this the end of the road and stated in his reply of April 12, 1929, to the Institute,

> The problem appears to the Board, therefore, due to the legal inhibitions, to be one in the real solution of which action must be secured from the different States. The Board recognizes that individual State action without coordination would not cover the question, but with a view to bringing about such a program and its coordination, the Board believes it would be worth while to renew discussion with the three or four principal oil-producing States, particularly to learn if it is not possible for them to enter an interstate compact * * *.

with the Federal Government, through congressional action, as a party. The idea was not new in 1929, as it had been proposed by the Board in 1926; and further back, in 1923, Mr. Justice Brandeis, in a dissenting opinion in *Pennsylvania* v. *West Virginia*,[7] had pointed out the need for an interstate agency if the gas supply of a region was to be equitably apportioned.

In 1931 the proposal of an interstate compact was presented to the Board by the Oil States Advisory Committee.[8] A few months later Oklahoma, Kansas, and Texas entered into an informal compact setting the quotas for each State's production for 1932 and the remainder of 1931. During the period from September 1930 to the end of 1932 volunteer committees on petroleum economics, at the request of the chairman of the Oil Conservation Board, proposed a series of estimates of national petroleum requirements for the guidance of the States and the industry. From midyear 1931, the average posted price for average quality Midcontinent crude rose from 18 cents per barrel to 92 cents in April 1932, but in spite of some postings as high as $1.04 in October 1932, the pressure of oil on the market pushed the price downward, and the year 1933 found crude below 50 cents. The improvement in markets that had been achieved during the initial days of proration was lost, and the industry was practically back where it had started from. Increased potentials, more and more wells, decreasing allowables, lower prices, the need for more oil at lower prices to pay off the costs of drilling and production, bootlegging oil produced in excess of allowables—together constituting a vicious circle and giving rise to complete chaos—demanded strong remedies. Despite various State efforts to curb production, which included cases of armed intervention,[9] it was clear by January 1933 that curtailment efforts had been unsuccessful and that the industry faced a crisis. It was argued in some quarters that proration had been a mistake and that had the new fields been allowed to produce without restriction their period of flush production would have been passed and, therefore, that these fields would no longer represent a potential threat. It was also argued that additional price cuts would make it impossible to enforce production allowables, since producers would have to get increased volume if they could not get increased price.

Price reductions on crude oil about the middle of January 1933 spread rapidly over practically all the oil-producing States east of California, and on January 20 the United States Senate directed a resolution to the Federal Trade Commission to report on the cause of the recent cut in the price of crude petroleum and petroleum products and on other associated questions.[10] The statistical committee of the American

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[7] 262 U. S. 553, 623.

[8] The committee was made up of officials of oil producing States, principally of the Midcontinent, and was the result of a conference of the Governors of Oklahoma and Texas with representatives of the Governors of Kansas and New Mexico, February 28, 1931.

[9] On December 12, 1932, the Supreme Court of the United States set aside orders issued by the Governor of Texas to the State Militia for reducing oil production in the east Texas field.

[10] No formal report was made as funds were not available and no investigation could be started without a concurrent resolution of the two Houses of Congress.

Petroleum Institute and the volunteer Committee on Petroleum Economics issued forecasts in which it was anticipated that the crude oil demand during the first 6 months of 1933 would be somewhat lower than during the corresponding period of the preceeding year.

The crisis in the oil industry was brought to the attention of the Secretary of the Interior, who invited the Governors of the oil-producing States to a conference on March 27, 1933, to see if anything could be done within the law to limit production of oil to assure a fair price to producers and to put the industry on a sound basis. In his opening remarks at this conference, the Secretary briefly commented on the unsuccessful attempts of the States to balance supply and demand and on the maze of confusion and conflicting interests out of which—

> must come a means of control or limitation of production that will assure a continuing, adequate domestic supply of oil that will not and must not exceed actual consumption requirements.

There was no consensus at this conference so two reports resulted: one by the Committee of Fifteen,[11] another by a group known as the Independent Petroleum Association Opposed to Monopoly. The extensive report of the Committee of Fifteen included in paragraph 3 a recommendation that—

> The President of the United States should be requested immediately to recommend to the Congress the adoption of a law prohibiting the transportation in interstate and foreign commerce of any oil or the products thereof produced or manufactured in any State in violation of the laws thereof. * * *

The reports submitted to the Secretary were transmitted to the President, who, on April 3, 1933, wrote to the Governors of the States that had been represented at the conference. In considering the recommendations, he stated, in part—

> The Committee of Fifteen in paragraphs A-3 and A-4 recommend certain action on the part of the Federal Government. I am of the opinion that the suggestion that the Congress pass legislation prohibiting the transportation in interstate and foreign commerce of any oil or the products thereof produced or manufactured in any State in violation of the laws thereof, is well considered. I am prepared to recommend such legislation to Congress as a contribution on the part of the National Government toward the solution of the difficulties in which the oil industry finds itself.

During the week of the Governors' conference in Washington, the production of the East Texas oil field increased very markedly, and the national production for the week ending April 1 was 600,000 barrels a day higher than the production recommended by the conference (2,000,000 barrels daily). The peak of tank-car shipment from the East Texas field, since the open-flow period during the summer of 1931, was reached April 1, 1933. Oil prices as low as 13 cents a barrel were reported, although the posted price was 50 cents. The opinion was expressed that even those most active in the illegal production of crude oil felt that their days were numbered, as "Washington" would do something to stop their practices. Consequently, the quantity of illegally produced oil rose to a high figure.

In the Oklahoma City field, wells in the Wilcox sand were shut down on April 1 and the whole field on April 5 for new potential tests under the proration law then under legislative consideration, which was enacted April 10.

The East Texas field was shut down from April 6 to April 24. In ordering this, the third shut-down of the field, the Texas Railroad Commission was reported to be awaiting the action of the State legislature relative to the marginal well provisions of the State conservation laws,[12] as it was apparent that the allowable under the law extant would have greatly exceeded the 400,000 barrel allowable. The new order of the railroad commission, effective April 24, recognized the 40 barrel marginal minimum with an addition of 15 percent based on flowing capacity. East Texas under this order was allowed 750,000 to 850,000 barrels daily or as much as was recommended for the entire State at the Governors' conference. The effect on the price of crude oil was drastic. East Texas crude oil dropped to 10 cents, and this drop was followed by general price reductions throughout the entire producing area east of the Rocky Mountains.

The magnitude of illegally produced crude oil in East Texas is not known exactly, but from the Texas Railroad Commission figure of 838,900 barrels as the average daily allowable for May 1933 and the United States Bureau of Mines figure of 992,700 as the daily average production, it appears that the indicated illegal production averaged 153,800 barrels daily. The excessively high withdrawals of oil caused a decline in reservoir pressure of such magnitude that it was freely predicted a similar continued decline would find two-thirds of the wells on the pump by the end of the year. This belief was so strongly held that at least $15,000,000 worth of pumping equipment was shipped into the East Texas field during the year.

The impact of the East Texas situation was felt in Congress through the introduction of the Capper bill in the Senate, May 19, 1933, and the Marland bill in the House, May 20, 1933;[13] the intent of which was

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[11] The Committee of Fifteen was a merger of three committees to represent, (1) the Governors of the oil-producing States or their duly authorized delegates, (2) the oil and gas associations representing independent producers of oil and gas in the United States, and (3) the major oil and gas and importing companies.

[12] The Texas law in effect prior to the shut-down exempted marginal wells if not producing more than 40 barrels daily.

[13] H. R. 5720, the Marland bill, and S. 1736, the Capper bill, were identical bills

> to preserve and protect the correlative rights of the oil-producing States, to assist them in the proper enforcement of their oil conservation laws, to assure the conservation of crude petroleum and natural gas and to preserve the same as national resources, and to regulate the transportation and sale in interstate and foreign commerce of natural gas, crude petroleum, and the products thereof; to prevent waste in the production, marketing, and use of such natural gas and petroleum; to invest the Secretary of the Interior with power to carry out this Act, and for other purposes.

Congressman Marland also introduced a bill, House bill 5010, April 14, 1933,

> to aid the States in the conservation of crude petroleum and to prevent the transportation in interstate and foreign commerce of crude petroleum which has been unlawfully produced.

During the same period legislation, later to be known as the National Industrial Recovery Act, was being considered. On May 20, 1933, the President addressed letters to the Senate and to the House relative to incorporating in the recovery bill certain special provisions on oil. The President referred to the serious condition of the oil-producing industry, the interest to the Nation that oil production should be under reasonable control, and the difficulty, if not impossibility

> to bring order out of chaos only by State action.

He requested that the subject be given immediate attention, and in order to save time,

> it might be possible to incorporate action relating to the oil industry with whatever action the Congress desires to take in regard to the other industries.

The recovery act as then contemplated did not give the President powers to regulate the oil industry. The Secretary of the Interior, therefore, at the hearing on the Capper-Marland bill stated that he had been authorized to say that the President

> hopes very much that there will be attached to the national industrial recovery bill the following amendment:
>
> "CONSERVATION OF PETROLEUM
>
> "SEC. 10. For the oil industry, in addition to the powers granted the President concerning codes of fair competition, agreements and licenses, he is authorized to prescribe regulations to supplement State conservation legislation regulating the production of petroleum, to allocate equitably the national market demand for petroleum and the products thereof among the oil-producing States and between domestic production and importations and to prohibit the transportation in interstate commerce of petroleum and the products thereof produced or withdrawn from storage in violation of any State or Federal law or the regulations prescribed thereunder."

The amendment as proposed was altered during its consideration by Congress and emerged in the N. I. R. A. as Sec. 9, the first two paragraphs dealing with pipe lines and the third paragraph, 9 (c), with the prohibition against the transportation in interstate and foreign commerce of oil produced or withdrawn from storage in violation of State law. As approved, the amendment was as follows:

> OIL REGULATION
>
> SEC. 9. (a) The President is further authorized to initiate before the Interstate Commerce Commission proceedings necessary to prescribe regulations to control the operations of oil pipe lines and to fix reasonable, compensatory rates for the transportation of petroleum and its products by pipe lines, and the Interstate Commerce Commission shall grant preference to the hearings and determination of such cases.
>
> (b) The President is authorized to institute proceedings to divorce from any holding company any pipe-line company controlled by such holding company which pipe-line company by unfair practices or by exorbitant rates in the transportation of petroleum or its products tends to create a monopoly.
>
> (c) The President is authorized to prohibit the transportation in interstate and foreign commerce of petroleum and the products thereof produced or withdrawn from storage in excess of the amount permitted to be produced or withdrawn from storage by any State law or valid regulation or order prescribed thereunder, by any board, commission, officer, or other duly authorized agency of a State. Any violation of any order of the President issued under the provisions of this subsection shall be punishable by fine of not to exceed $1,000, or imprisonment for not to exceed six months, or both.

Effective June 13, 1933, the Texas Railroad Commission issued a new East Texas order reducing the allowable to 550,000 barrels or about 300,000 barrels less than the prior order. Crude oil prices responded with increased postings.

The recovery bill became a law June 16, 1933, and its effect was almost immediately felt in a general increase in oil prices.

The President on July 11, 1933, issued an order applying his authority over oil produced or withdrawn from storage illegally,[14] and three days later delegated his authority to the Secretary of the Interior.[15] The Secretary of the Interior on July 15, 1933, issued general regulations prohibiting the movement of oil in interstate and foreign commerce except upon affidavits certifying as to the oil having been produced or withdrawn from storage as prescribed by State laws or regulations.[16]

Before considering the transition from the "affidavit period" in the application of section 9 (c) to the "Tender Board period," mention should be made of Petroleum Code activities which, because of their supplemental effect, are often confused with activities under section 9 (c). This confusion is readily understood when it is recognized that the Secretary of the Interior was the Administrator of both section 9 (c) and the Petroleum Code[17] and thus worked on both problems, often simultaneously.

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[14] Executive Order No. 6199, July 11, 1933.

[15] Executive Order No. 6204, July 14, 1933, authorized the Secretary of the Interior to exercise all the powers vested in the President for the purpose of enforcing sec. 9 (c) of the N. I. R. A

[16] The first order was of national application but by a superseding order of August 2 the areas of its application were restricted to Oklahoma City and the East Texas fields.

Hearings on the Code of Fair Competition for the Petroleum Industry began on July 24, 1933, and on August 19 the President approved the code, which became effective September 2. The psychological effect of the approval of the code must have been powerful, as the posted price of east Texas crude advanced to 60 cents per barrel on August 24 and to 75 cents on September 6. On the effective date of the Administrator's order, September 8, 1933, allocating consumer demand among the oil-producing States, the posted price of East Texas crude advanced to 90 cents.

Although there were sections in the oil code on refining, marketing, and wages and hours, certainly the emphasis, both at the hearings and in the work of the Planning and Coordination Committee, the industrial code authority, at the outset was on production. There seemed to be a motivating philosophy in the then commonly accepted point of view that all that was necessary was to straighten out the problems of production and everything else would take care of itself. That this idea was erroneous is beside the point so far as the early activities of the industry under the code are concerned. The code provided a means by which market demand could be allocated to the producing States.[18] The second allocating order, effective September 28, 1933, was followed the next day with a posted price for East Texas and average Midcontinent crude oil of $1.00, which remained fixed until January 9, 1936.

During the code period, imports of petroleum and its products were held down. Withdrawals of crude oil from storage were controlled: allocations were followed within an average of 4.7 percent (excess);[19] and production was held at a comparatively flat level, relatively free from wide seasonal fluctuations: studies were conducted on the costs of crude oil production;[20] and 353 plans for the orderly development of new pools were approved.[21]

Returning now to a consideration of section 9 (c), the gradual increase in the amount of crude oil produced in excess of allowables during the summer and fall of 1934, particularly in East Texas, where the State regulations proved inadequate to the task of restricting production to conform with State allocations, proved that the affidavit system as a method of control was not effective. It was only transitional in the development of certain legal principles and of the tender system which was later carried into the Connally law. Consequently, the affidavit system need not be analyzed in detail.[22] When this system, requiring affidavits of legality with shipments, was inaugurated, it was almost immediately attacked and made inoperative by a decision of the district court, but a decision of the court of appeals upheld the power of the Government to require reports and the validity of the section. This permitted reestablishment of Federal enforcement in East Texas. Despite changes made in the system, "hot oil" producers, by the use of fraudulent affidavits and by failing to make them, continued to operate in violation of the law. Then, too, the system was inadequate when it came to proving violations in the courts; this, for practical purposes, led to its abandonment and the organization of the Federal Tender Board, in October 1934, as a new means of enforcement. Under the regulations of the Board, certificates of clearance, issued by the Board, were required as a condition precedent to the movement of petroleum and petroleum products in interstate and foreign commerce out of East Texas.

The tender system, which in its mechanics is very much like a banking operation, that is, the establishment of credit and withdrawal against the deposit under control of the Board, with continuous auditing of accounts and field operation, worked well almost from its inception, and within a few weeks the flow of "hot oil" was definitely on the decline.

This first Federal Tender Board ceased functioning January 7, 1935, when the Supreme Court reversed the decision of the court of appeals in the *Panama* and

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[17] By Executive Order No. 6260-A of August 28, 1933, the Secretary of the Interior was appointed Administrator for the Petroleum Industry and the Department of the Interior was designated the Federal agency.

[18] Article III of the code containing provisions relative to the production of crude oil dealt with (1) limitation of imports of crude petroleum and petroleum products for domestic consumption; (2) withdrawals of crude oil from storage; (3) estimates of required crude oil production to balance consumer demand and allocation among the States; (4) relationship between representative crude oil and gasoline prices; (5) establishment of price schedule and determination of cost of production; (6) planned development of new pools.

[19] From September 1 to the end of 1933 production exceeded allocations 3.75 per cent; the increase to 6.74 in the first semester of 1934 followed by 4.36 in the second is explained in the fact that recognition was given to the relationship between refinery operations and estimated demand, e. g., refining of excess crude oil and shipment of products to other States for storage, distorted State impressions on magnitude of State demand for crude. The excess of production over demand was reduced to 3.55 per cent during last five months of code.

[20] See *Report of the Cost of Production Crude Petroleum*, published by Petroleum Administrative Board, Department of the Interior, December 1935.

[21] See *Operation of the New Pool Plans of Orderly Development Under the Code of Fair Competition for the Petroleum Industry*, published by Petroleum Administrative Board, Department of the Interior, April 1936.

[22] For further details see *Annual Report of the Secretary of the Interior* for the year ending June 30, 1935.

Amazon cases and declared section 9 (c) invalid because of improper delegation of legislative authority.

The opinion of the Supreme Court in the *Panama* and *Amazon* cases furnished the basis for action by Congress in the attempt to stop the movement in interstate and foreign commerce of oil produced or withdrawn from storage in violation of State laws or regulations. The Court, among other things, said:

> Thus in every case in which the question has been raised, the Court has recognized that there are limits of delegation which there is no constitutional authority to transcend. We think that section 9 (c) goes beyond those limits. As to the transportation of oil production in excess of State permission, the Congress has declared no policy, has established no standard, has laid down no rule. There is no requirement, no definition of circumstances and conditions in which the transportation is to be allowed or prohibited.

But, in creating an administrative agency—

> the legislature, to prevent its being a pure delegation of legislative power, must enjoin upon it a certain course of procedure and certain rules of decision in the performance of its function. It is a wholesome and necessary principle that such an agency must pursue the procedure and rules enjoined and show a substantial compliance therewith to give validity to its action * * *.

On January 8, 1935, the Oil Administrator announced the serious setback suffered in the Court's adverse opinion on section 9 (c) but added that—

> The decision of the Court, in my opinion, emphasizes the necessity for specific and adequate legislation to effectuate a rational conservation program designed to prevent the waste of oil and gas resources and to prevent the demoralization of one of our largest basic industries.

Senator Gore on January 10 introduced a joint resolution to amend section 9 of the N. I. R. A. and on January 14 Senator Connally introduced a bill—

> To regulate interstate and foreign commerce in petroleum and its products by prohibiting the shipment in such commerce of petroleum and its products produced in violation of State law and for other purposes.

Congressman Disney introduced a bill for similar purposes in the House on January 10. The Gore and Connally bills were redrafted and reintroduced to the Senate on January 18 as Senate bill 1190.[23]

The Annual Report of the Secretary of the Interior carries the story from the passage of the Connally law to the end of June 1935:

> On February 22, 1935, the Connally law was passed by the Congress, eliminating the defects found by the Court in section 9 (c) by specifically prohibiting interstate or foreign commerce in hot oil. Federal Tender Board No. 1 was established under this law on March 1, 1935, and shortly thereafter Federal Petroleum Agency No. 1 was set up under the same law to perform the administrative and investigative functions in connection with the applications for approved tenders filed with Federal Tender Board No. 1. The Federal tender system has functioned effectively since that time and has prevented any substantial movement in interstate commerce of hot oil or gasoline out of East Texas. This activity not only tended to check overproduction of crude petroleum but assisted in stabilizing the interstate refinery markets at a time when the intrastate Texas markets were thoroughly demoralized. Several attempts to enjoin the activities of the Board have been attempted without success.

With the adverse decision of the United States Supreme Court in the *Schechter* case on May 27, 1935, the administration of the Code of Fair Competition for the Petroleum Industry terminated and, with it, the supporting activities of that code in oil conservation. The Petroleum Administrative Board, which had assisted the Administrator in the enforcement of the code, was promptly reduced to a group that completed studies and research either under way or requested by the President, and on March 31, 1936, its duties were over.

Since the Secretary of the Interior, as Administrator of the Connally law, had had the assistance of the Petroleum Administrative Board during its existence in the administration of that law, he established the Petroleum Conservation Division as of April 1, 1936, to advise and assist him in the enforcement of the act. The Division is also authorized—

> to discuss the work of any agency dealing with oil and gas; recommend action on any case brought to its attention; coordinate information; and, through appropriate channels, act as the contact agency with the Interstate Oil Compact Commission; present required data to the Congress; attend oil and gas conferences in which the Department is interested; cooperate with the oil-producing States in the study of physical waste and the enactment of uniform oil and gas conservation laws; and contact other departments of the Government whose work deals in any measure with oil and gas.

While the Connally law is applicable in any State having a law regulating the production of petroleum, to date the tender system has been used only in the East Texas oil field where it has been found to be necessary.[24] Without elaborating at length on the problem presented by the East Texas oil field, it should be noted in passing that this field has the largest potential of any field in the United States and produces from its 25,000 wells approximately 170,000,000 barrels of crude oil annually, of which about 90 percent moves from the field to the Gulf coast. The task of the Tender Board in clearing legal oil and products from the field involves the investigation of about 6,000 applications for tenders annually at a cost of less than one-tenth of a cent per barrel.[25] Approval has been withheld on only about 1 percent of the oil for which applications have been received, which would seem to indicate that the system is so thorough that applications for tenders are not submitted unless the applicant has a reasonable basis for assuming the legality of the oil involved.

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[23] The debate in the Senate on the bill was generally legalistic as to the constitutionality of legislation controlling commerce as between the States (*Congressional Record*, January 21 and January 22, 1935). In the House the debate, fortified by intimate knowledge of the problems of the oil industry as a result of the Petroleum Investigation of the subcommittee of the Committee on Interstate and Foreign Commerce on H. R. 441, during late 1934, was more strongly directed to the question of why it was necessary for the Federal Government to cooperate with the oil States in the enforcement of State conservation laws and the need of conservation. The debate in the House also discloses that there was a considerable sentiment for more comprehensive legislation on oil conservation than that covered by S. 1190, which was the bill under consideration. (*Congressional Record*, February 18, 1935.)

[24] See Executive Order No. 7758, December 2, 1937.

Oil fields other than the East Texas one are under constant observation by investigators of the Tender Board and the Petroleum Conservation Division and no crude petroleum or petroleum products are permitted legal shipment from the Gulf coast (Texas and Louisiana) without reports [26] to the Conservation Division concerning the origin and State orders under which it moves.

The Connally law, which was to have expired by limitation on June 16, 1937, was extended by amendment (Public, No. 145, 75th Cong., 1st sess., S. 790) to June 30, 1939.

The operation of the Connally law has demonstrated a method by which the State and Federal Governments may work together to prevent the waste of petroleum resources and increase the ultimate recovery of oil.[27] In East Texas alone this method of joint action by the State and Federal agencies is said to have raised the estimates of the recovery of oil from the field at least 30 percent. Such an increase would amount to about 600,000,000 barrels, which would be equal to the discovery of 60 average oil fields.

The Connally law has been criticized by two groups, those who want unrestricted production and those who take almost the opposite position and advocate a law providing for Federal control. Those who want unrestricted production charge that the law is monopolistic in character and inimical to the interests of small refiners and nonintegrated marketers. Pending an unequivocal legal interpretation of the word "monopoly," it is perhaps fair to say that the word generally carries with it the idea of an exclusive right of selling or purchasing or controlling the supply of a given commodity or service in a given market, which enables the one having the control to raise the price of the commodity or service above the price fixed by free competition. The Connally law has destroyed no element of fair competition that existed prior to its passage. No State has appeared sufficiently self-effacing to remove itself from the urge to meet market demand, and no company has decided that it does not want more volume. The price of petroleum has been both higher and lower during the period of the law than it was prior to its enactment. The law has made it difficult and nearly impossible for refiners to get "hot oil" and for marketers to get products manufactured from "hot oil," and to that extent it has a stabilizing influence, but it has not eliminated the competitive advantages as between oil-producing regions—quality, cost of production, and position with respect to markets. Because refiners and marketers have not been able to solve their problems by resort to the Connally law, it does not follow that their problems are the outgrowth of the law, for they are essentially the same as they were before the passage of the act.

Those who think the law should be replaced by one establishing Government control argue that the States are not capable of handling the problem. This point of view is not accepted by any large number of the industry and is strongly opposed by practically all of the oil-producing States.

During the past three years, the States and the Federal Government, working together, have gradually evolved the basic principles of a procedure for oil conservation. It is the opinion of the Secretary of the Interior, as stated in his telegram to the Chairman of the Interstate Oil Compact Commission, July 28, 1938, that

> If the ground which has so effectively been gained is not to be lost, we soon must be prepared to utilize this experience in making recommendations as to future action which should lead ultimately to the establishment of a permanent oil conservation policy for the United States, based on mutual respect for our separate and joint responsibilities and having the prime purpose of assuring an adequate supply of oil at reasonable prices.

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[25] For details of operation, see *Annual Report of the Secretary of the Interior* for the years 1936 and 1937.

[26] Executive Order No. 7757, regulation XVIII.

[27] For a more detailed discussion, see the statement of the Secretary of the Interior at the Senate hearings on the extension of the law. *Hearings before a subcommittee of the Committee on Finance*, U. S. Senate, 75th Cong., 1st sess., S. 790 (p. 7).

PART FOUR—SECTION III

PETROLEUM PRODUCTION— EXPERIENCE OF THE STATES IN CONTROL AND CONSERVATION MEASURES

CHAPTER 1.—THE INTERSTATE OIL COMPACT

By John W. Frey [*]

The interstate compact to conserve oil and gas was executed in Dallas, Tex., February 16, 1935, and was subsequently ratified by the States of New Mexico, Kansas, Oklahoma, Illinois, Colorado, and Texas.

The declared purpose (art. II) of this agreement between the compacting States is—

> to conserve oil and gas by prevention of physical waste thereof from any cause.

Each state agreed (art. III) that within a reasonable time it would enact laws, or if enacted to continue the same in force—

> to accomplish within reasonable limits the prevention of—
>
> (*a*) The operation of any oil well with an inefficient gas-oil ratio.
>
> (*b*) The drowning with water of any stratum capable of producing oil or gas, or both oil and gas, in paying quantities.
>
> (*c*) The avoidable escape into the open air or the wasteful burning of gas from a natural-gas well.
>
> (*d*) The creation of unnecessary fire hazards.
>
> (*e*) The drilling, equipping, locating, spacing, or operating of a well or wells so as to bring about physical waste of oil or gas or loss in the ultimate recovery thereof.
>
> (*f*) The inefficient, excessive, or improper use of the reservoir energy in producing aay well.

In article IV, the States agreed to deny access to commerce to oil produced in violation of State conservation laws and to provide penalties for the waste of oil or gas.

Article V provides:

> It is not the purpose of this compact to authorize the States joining herein to limit the production of oil or gas for the purpose of stabilizing or fixing the price thereof, or create or perpetuate monopoly, or to promote regimentation, but is limited to the purpose of conserving oil and gas and preventing the avoidable waste thereof within reasonable limitations.

Article VI provides for a commission with the duties of making inquiries concerning the conservation and prevention of the physical waste of oil and gas, to recommend the coordination of the exercise of the police power of the several States to promote the maximum ultimate recovery from the petroleum reserves, and to recommend measures for the maximum ultimate recovery of oil and gas.

The idea of an interstate compact on oil more comprehensive than the compact now in force was brought to the attention of the oil producing States in 1932 by the Secretary of the Interior, who was also the chairman of the Federal Oil Conservation Board, and in 1935 the subcommittee of the Committee on Interstate and Foreign Commerce of the House of Representatives, which investigated the oil industry under House bill 441 during 1934, encouraged the formation of a compact.

At a meeting of Governors and Governors-elect and representatives of Governors, held at Ponca City, Okla., December 3, 1934, various resolutions looking to the formation of an interstate oil compact were offered. The original resolution introduced at the second meeting, January 3, 1935, recommended the enactment of Federal legislation that would have (1) created a Federal fact-finding agency to determine the demand for petroleum and the allocation of required domestic production to the States, (2) authorized a Federal agency to restrict imports in accordance with the findings of the fact-finding agency, (3) authorized a Federal agency to prevent the movement of oil produced in violation of State laws, and (4) made possible an interstate agreement whereby the States would undertake (a) to participate in the joint fact-finding agency, (b) to receive and consider the agency's findings and to make them effective within the States, and (c) to cooperate in the study and recommendation of uniform conservation laws and regulations. This resolution was favored by California, New Mexico, Kansas, Oklahoma, and Illinois, but was not acceptable to Arkansas, Louisiana, and Texas. The Texas representatives at the conference expressed the thought that the compact should (1) be permissive only, (2) confine the States to the consideration of conservation (prevention of physical waste of natural resources), (3) recognize that the right to control the production of crude petroleum is a matter exclusively within the jurisdiction of the several producing States, and (4) specifically prohibit the States from entering into any compact which has as its purpose price fixing, the creation of or perpetration of monopoly or regimentation.

Failing complete agreement at the second meeting, a third and successful attempt at the formulation of a compact was made at Dallas, Tex., February 15 and 16, 1935. This compact was ratified by New Mexico in

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February, by Kansas and Oklahoma in March, by Texas and Colorado in April, and by Illinois in July. Since the compact could become effective by the consent of Congress after three States had ratified, the compact was submitted to the Federal Government for approval during April.

The subcommittee of the Committee on Interstate and Foreign Commerce of the House, which had conducted the petroleum investigation under House bill 441 during late 1934 and early 1935, did not submit a complete report until the Committee on Interstate and Foreign Commerce reported on House bill 9053, August 13, 1935. That bill contemplated, (1) the consent of Congress to the State Oil and Gas Compact, and (2) the establishment of a Petroleum Administrative Board to collect data on the petroleum industry, to study and investigate matters relating to the petroleum industry, to determine periodically the reasonable market demand for petroleum and that part which should be produced in each State, to administer the act of February 22, 1935, 49 Stat. 30 (the so-called Connally "hot oil" law), to make determinations concerning conditions of import and recommendations concerning import control which was vested in the President, and to consolidate the Federal activities relating to oil. This bill also contemplated the formulation of voluntary agreements between members of the petroleum industry with the assistance of the Board and the consent of the President.

In commenting on the compact phase of the bill, the committee said (Report No. 1801, 75th Cong., 1st sess.):

> We strongly urge upon the oil-producing States the adoption of State compacts to deal with the problems of the production of petroleum with which individual States are powerless to cope. The subcommittee clearly recognizes the principles of State compacts for the purpose of effecting a common end of State interests. * * * State compacts, flexible in operation and over which the President of the United States or a Federal agency in the interest of the consuming masses of the Nation, may hold some veto power, is a solution of those problems of petroleum production which cannot be solved by modification of the "law of capture" and other legislation operating within State boundaries. We are confident that the Governors of the oil-producing States and the majority of the industry within those States, are cognizant of the common-sense theory that waste of petroleum resources must be prevented.

Public Resolution No. 64 of the Seventy-fourth Congress, approved August 27, 1935, included only that portion of the bill which consented to the Compact.

The Compact, by its own terms, was to be of 2 years' duration, expiring by limitation on September 1, 1937, although any member State was permitted to withdraw upon 60 days' notice. None of the member States has withdrawn and the legislature of each and Congress (Pub. Res. No. 57, 75th Cong.) have ratified the extension of the Compact to September 1, 1939.

Conformity to the conditions of the Compact has not been uniform on the part of member States. Kansas, New Mexico, and Oklahoma, prior to the approval of the Compact, enacted permanent legislation which meets substantially the requirements of article III to prevent the operation of any oil well with an inefficient gas-oil ratio, excessive or improper use of reservoir energy in producing a well, and other enumerated causes of physical waste. The State of Texas has continued legislation until September 1, 1939, in conformity with that article. The conservation statutes of Colorado and Illinois (which do not have expiration dates) only partially meet the conditions of article III. In other oil-producing States, not members of the Compact, oil and gas conservation statutes in conformity with the principles of article III have received attention. In Louisiana a conservation law was passed in July 1936, but in California, Michigan, Mississippi, and Arkansas proposed legislation was not enacted. Arkansas established a Board of Conservation under Act 234 of the General Assembly (1933) and has applied that authority to the regulation of oil production.

Under the terms of article IV, oil produced in violation of State laws or orders was to be denied access to commerce, and stringent penalties against the waste of oil and gas were to be imposed. These conditions have been met by New Mexico, Kansas, and Texas, but Colorado, Illinois, and Oklahoma have not fully met them. The statutes of Louisiana, a nonmember State, conform to the article.

The Compact specifically provides in article V that it is contrary to its purpose to limit the production of oil or gas for the purpose of stabilizing or fixing the price or to create or perpetrate monopoly or to promote regimentation. The transcripts of the meetings of the Interstate Oil Compact Commission reveal no action taken by the Commission contrary to these restrictions.

Although no mention is made in the Compact of the allocation of petroleum production as between the compacting States, the Texas Senate on May 7, 1937, shortly after the ratification of the extension of the Compact, adopted a resolution authorizing the Governor of Texas to cancel and annul Texas membership in the Compact at any time that State is not allotted its reasonable and proportionate share of the production of oil.

The organization of the Compact Commission was effected at the meetings of September 12 and October 11, 1935, at which four permanent committees, (1) conservation, (2) coordination, (3) consumption, and (4) imports and exports, were appointed.

The duties of the Committee on Conservation—

> shall be to make a study of the most improved methods for the conservation of oil and gas resources, of the conservation statutes of the various States and of the means and methods of

> administering them, and from time to time to report thereon, with such pertinent facts and suggestions as it believes may be helpful to the Commission in formulating recommendations to the various States in the matter of conservation.

This committee, subsequent to a preliminary report, has devoted most of its efforts to the initiation of a compilation and codification of the conservation laws and regulations of the various oil and gas producing States. At the meeting of March 13, 1936, the committee reported on a study ("Indexes") of the oil and gas laws of 19 oil producing States that had been made by a subcommittee. A summary statement covering the matters which the subcommittee, after studying these laws, considered of greatest importance to the cause of conservation was presented under the title "Need of Conservation Legislation." Among other things, this report pointed out that—

> conservation has been restricted and hampered by failure to have more uniform State laws and regulations—

and suggested that—

> legislatures should authorize their State Regulatory Agency to cooperate with similar Agencies of adjoining States for conservation purposes in all fields crossing State lines.

Other subjects commented on were: effects of public opinion, conservation of reservoir energy, well spacing, drilling control, drilling regulations, unit operation, proration, ratable taking, determination of allowable, and repressuring. The Department of the Interior, through the Petroleum Conservation Division, cooperated with the committee in the preparation of the Indexes.

A progress report and a tentative "comparison of the oil and gas laws (20 States and U. S. Public Lands)" was presented at the meeting of July 31, 1936. At the meeting of October 2, 1936, it was reported that the committee had not been able to make very much progress in the codification of the conservation laws and regulations of the various oil and gas producing States, as it was handicapped by lack of funds to carry on the work expeditiously. The committee, at the meeting of December 1, 1936, reported its expectation of being able to prosecute a little more vigorously its compilation and codification of the conservation laws.

The Committee on Coordination at the organizing meeting was assigned the duty—

> (1) to ascertain as accurately as possible the aggregate potential production of either oil or gas, or both, of each member State, and the percentage thereof actually being produced; (2) to report periodically as often as the Commission may direct, an estimate of the proven petroleum reserves, including the above ground storage, for the United States, together with a statement of the method and manner of preparing such estimates; and (3) to recommend plans whereby the producing ability of wells may be more correctly and uniformly determined among the member States and incorrect estimates of well potentials eliminated as far as possible.

At the meeting of March 13, 1936, this committee submitted a provisional report on potentials and a comparison of the Federal recommended market demand with the potentials. While there is no evidence in the reports of subsequent meetings that other reports on potentials were prepared by the committee, the Governor of Oklahoma has had two reports prepared on his own initiative, the so-called McCoy estimates, under the dates January 6, 1938, and September 6, 1938, which he has given to officials of the oil-producing States for their consideration.

At the meeting of July 31, 1936, the Commission adopted a resolution of this committee recommending that the Department of the Interior, pursuant to the Connally Law, should continue to collect and distribute to State enforcement agencies current information on tanker and barge shipments of crude petroleum or petroleum products in interstate commerce. Such reports, to the extent which may prove practical, should provide information which will permit State and Federal administrative officials to make certain that crude petroleum, or petroleum products offered for shipment, was not produced, withdrawn from storage, or transported in excess of the amounts permitted under the laws of the State in which said petroleum was produced.

At the meeting of October 2, 1936, this committee reported that the Conservation Commission of Louisiana (not a member of the Compact) and the Railroad Commission of Texas were—

> working in perfect harmony in the prevention of actual physical waste—

in the Rodessa Field, which at that time was about equally active in the two States.

The third committee, the Committee on Consumption, was given the responsibility—

> to study and report upon the methods used in determining the current consumption and demand for petroleum and petroleum products, or of gas, including the methods used by the Bureau of Mines, with a view to promoting accuracy in estimates of market or consumption demands.

At the Compact meeting December 13, 1935, a resolution was adopted in which it was recommended to the regulatory bodies of all the oil producing States that they receive in evidence the periodical findings of the United States Bureau of Mines with reference to consumption and supply and demand, and that this evidence be given proper and due consideration by the State regulatory bodies.

Representatives of the committee from Texas, New Mexico, Oklahoma, and Kansas conferred with the Bureau of Mines January 7 and 8, 1936—

> in order to give the Commission a better understanding of the methods of compiling the Bureau of Mines statistics and the making up of their estimates.

In reporting, March 13, 1936, the committee states it was—

> convinced that the statistical methods by the Bureau are sound in principle and are applied in an impartial manner. We feel it is highly essential that this work go forward in the hands of an unbiased fact-finding agency like the Bureau of Mines, and that it be adequately financed and in a manner that will keep it free from influences that would detract from its accuracy and impartiality.

In the conference it was pointed out that the determination of the proper withdrawals from and additions to crude oil in storage was one of the most troublesome features of the Bureau's forecast work, largely because of inadequate data on stocks. An outgrowth of discussion on this subject led to a recommendation that the Bureau of Mines make a study to cover—

> both the economic and technical phases, so that the final report would show, not only the actual stocks and desirable stock levels in the various States, but also breakdowns according to grades of oil as determined by measurements of gravity and by distillation analysis.

Representatives of the Compact Commission and others interested in the oil industry presented the matter before a subcommittee of the House Committee on Appropriations, and the Seventy-fourth Congress provided the funds for the Bureau of Mines to make a survey of the crude oil held in storage above ground and to determine the quantities and characteristics of the light fractions contained in the various stocks. A preliminary report on the Bureau's findings was made at the Compact Commission meeting July 12, 1937, and the complete report was released at the Compact Commission meeting September 29, 1938.

The fourth of the original committees was charged with the duty "to make a study of the question of imports and exports." From the record of meetings it appears that this committee has made only one report, December 13, 1935, which stated—

> imports of petroleum have a very important influence on the domestic situation, and therefore must be taken into account in planning the proper conservation and development of the petroleum industry. We find that large imports are quite sure to have a harmful effect on the domestic situation by preventing the normal and efficient development and conservation thereof. We believe the ideal for which the Interstate Compact Commission is working is to conserve the petroleum resources of this country to the end that there shall be, for the longest possible time in the future, an abundant supply of petroleum in the nation at a reasonable cost to the consumer.

From the organization meeting of October 11, 1935, the four committees described were not increased until the meeting of April 29, 1938, when an Advisory Committee on Economics and a Committee for Forecasting Market Demand were appointed. Both of these committees reported to the Compact Commission meeting July 29, 1938, the first primarily on economic conditions and objectives of the oil industry, the other on an analysis of the Bureau of Mines' method of forecasting.

Considering the action of the Compact Commission as a whole it may be said that it has afforded an opportunity for broadening the interest of State officials, the oil industry, and, to an extent, the public in true conservation. The quarterly meetings, with their open forum of representatives of the State governments and the industry, undoubtedly have accomplished much in the way of creating understanding of the problems of administration and enforcement of the State conservation laws, on the one hand, and of problems of the industry, on the other. It is, however, difficult to measure the value of such contacts in anything but a qualitative way. While no mechanism exists in the compact to allocate the demand for petroleum as between the member States, it is entirely possible that the informal association of State officials dealing with common problems exerts some influence in each State in the determination of its total allowable.

The Compact has provided a mechanism that should contribute to the conservation of oil and gas; although not as much has been done in this direction as might have been hoped, the educative process has been continuous and probably not without desirable consequences. The Compact is not a panacea for the industry in all of its economic ramifications, and such was not its justification; yet in general, to date, it appears that there has been greater stability in the production branch of the industry than in refining or marketing. That the economic ills of refining and marketing are traceable in part to the operation of the Compact is a claim made in certain quarters. If the Compact were considered as an instrument for securing economic stability, which, incidentally, is denied by its own language, it would have to rest on the theory that to control production would automatically control all the other branches of the industry. This concept is obviously delusive, as there is in the Compact no provision for a buffer to prevent disturbances in marketing or refining from ultimately affecting the economics of production.

Several member States and some critics in no way connected with the Compact have registered complaints against the Compact because it has "no teeth," that is, nothing to compel member or nonmember States to follow recommendations of the Commission. This argument is usually met by the statement that the Compact is not intended to and cannot supersede the sovereignty of the State and that the basic principle is not coercion but cooperation. The same answer is used when the criticism is made that the Federal Government should be a member of the Compact, only in this case a statement is added to the effect that the police power is where it should be, within the State.

Some producers maintain that the Compact is responsible for their allowables not being "what they should be." To the extent to which inequities may exist either within a State or as between one and other States, this criticism is of doubtful merit, as the member States have not agreed to any system of allowables and, obviously, the Compact is without force in nonmember States.

The real test of the Compact is not deducible from economic conditions within the industry but from the extent to which it has succeeded in the prevention of physical waste, an objective which it had specifically delegated to itself. In the realization of this objective much remains to be done.

CHAPTER 2.—THE BUREAU OF MINES FORECASTS OF DEMAND FOR MOTOR FUEL AND CRUDE OIL

Alfred G. White*

For many years the relation between petroleum supply and demand has been recognized as a matter of primary national concern.

A study of the history of State oil conservation laws and of the operation of State enforcement agencies indicates clearly the evolution of the concept of preventing physical waste by maintaining a reasonable balance between current production and market demand for crude petroleum.

The prevention of excessive and premature flush production from new fields maintains essential gas pressure, lengthens the producing life of the wells, increases the volume of ultimate recovery, and avoids unnecessary and wasteful surface storage of crude petroleum.

Improvements in above-ground storage facilities have reduced evaporation losses, but substantial waste still exists, even under the best conditions, and indicates the desirability of the policy of holding reserves under ground until needed.

The tremendous increase in the demand for petroleum products has emphasized the relative inadequacy of our national reserves and the need for maintaining an economic balance between the flow of raw materials and the sale of finished products in the oil industry. As a result, intensive studies have been made of the longer-term trends of demand as well as of the adjustment of supply to meet current requirements.

The first forecasts of gasoline demand and crude-oil requirements were initiated by the Federal Oil Conservation Board in 1930, 1931, and 1932. These forecasts covered periods of either 3 or 6 months and were prepared by voluntary committees with which the Bureau of Mines actively cooperated. They were intended as a guide to assist in a proper national balance between production and consumption in the interests of conservation.

In the latter part of August 1933 the Petroleum Economics Division of the Bureau of Mines began supplying basic statistical data to the Petroleum Administrative Board for use in determining the allocation to the States of the allowable quantities of crude oil to be produced under the operation of the petroleum code, functioning under the provisions of the National Industrial Recovery Act. This cooperation continued until the Supreme Court's decision of May 27, 1935, terminated the effective operation of the code.

During this period the scope of the statistical work of the Petroleum Economics Division was expanded to include such additional current data as were necessary to project current consumption trends in the oil industry. Specifically, the following features were involved in this statistical service:

A monthly report showing crude runs to stills, crude-oil movements both interstate and intrastate, and a division of shipments according to method of transportation. This report is indispensable in State allocation work, is valuable to the Federal Government from the standpoint of national defense, to the industry as showing the sources of crude oil, and to the transportation agencies as basic data for measuring competitive trends.

A monthly report of crude-oil stocks by States of origin and location.

A weekly report of crude-oil stocks by grades to assist in furnishing a check on the current balance between production and demand.

A monthly report on data relating to the distribution of natural gasoline in order to trace the growth of sales in competition with refined gasoline.

These monthly and weekly services were separate and distinct from the monthly forecasts of demand and represented essential basic data to indicate the seasonal changes in demand and shifts in the sources of supply.

At the time of the termination of the petroleum code, active proration programs were in effect in several of the major oil producing States, operating under the authority of State conservation laws. The Governors of several of these States requested the Secretary of the Interior to have the Bureau of Mines continue its studies of market demand as an essential aid to the State conservation programs. Consequently, from June 1935 the Petroleum Economics Division began issuing monthly forecasts of demand.

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After the formation of the Interstate Oil Compact Commission in September 1935 that organization appointed a committee to confer with the Bureau of Mines as to the methods used in the preparation of the monthly forecasts. Representatives of the Commission later appeared before the House Committee, Interior Department Appropriations Bill, 1937, and urged that special funds be provided for the Bureau of Mines to continue the regular collection of current data on supply and demand, to issue monthly forecasts of motor fuel and crude oil demand, and to conduct a special survey of the quality and character of the stocks of crude oil in storage.

One important change has occurred in the forecasts as issued by the Bureau of Mines. Through October 1936 estimates were included for changes in crude-oil stocks, and, consequently, the final figures by States represented required production. In all forecasts subsequent to October 1936 no estimates for changes in crude-oil stocks have been made, and the figures by States represent market demand for crude which can be met either by new production or from stocks. The Bureau discontinued the estimates of crude stock changes at the request of a committee appointed by the Interstate Oil Compact Commission. Thus the present forecast estimates represent the total amount of crude oil required to meet the demand by States of origin and are not comparable with either State allowables or with production figures. In fixing their production allowables, certain States have at times exceeded the forecast estimates and built up stocks of crude oil or have set their allowables at lower figures to reduce crude stocks of State origin.

The monthly forecasts are of value to the Interstate Oil Compact Commission and the individual State agencies in establishing their conservation programs, to the industry as a guide to planning operations, and to the economic world in general in giving it a preview of trends in the oil industry.

The Bureau of Mines, because of its experience and the fact that it is authorized to collect the statistics for the oil industry, represents the logical agency to make such forecasts.

The Forecasts of Demand are purely a factual service rendered by the Bureau of Mines and represent an unbiased and scientific analysis of current demand on a monthly basis for the information of the Federal Government, the several State agencies, and the petroleum industry. They represent an estimate of the volume of current operations necessary to maintain a reasonable balance between supply and demand, with a view to avoiding unnecessary storage of either crude petroleum or refined products.

The forecasts of the Bureau of Mines are issued about the middle of each month to cover estimated requirements for the following month. They represent a short-term projection of all available information relating to seasonal production, stocks, sales, and consumption. The forecasts reflect actual competitive trends between States and make no adjustments for potential ability to produce.

The correlation of data on refinery sales and actual consumption is very difficult. Consumption of both motor fuel and fuel oils is subject to unexpected variations because of abnormal weather conditions. Sales may be shifted, as between months, by changes in price, freight rates, or export conditions. Part of the sales may actually represent stock accumulations at distribution points beyond the scope of stocks as reported to the Bureau of Mines. Frequently an expectedly large sales figure for one month will be normally offset by a correspondingly low figure for the next month. The combined forecast for the two months may be accurate, although not correct for either month separately.

Forecasts must be based on the assumption of normal weather conditions and the continuance of current trends as indicated by available data at the time of issue. For example, for a January forecast only slight information is available on December demand; only preliminary data based on current weekly statistics are available for November, and final statistics for October operations will have just been published.

The use of the term "market demand" for crude in the present monthly forecasts of the Bureau of Mines is restricted to the estimate of the actual demand for crude petroleum for export, for fuel and losses, and for the runs to stills required to supply both the demand for and normal seasonal stock changes of refined products.

The monthly forecasts of motor fuel demand can be added properly for a cumulative annual total for comparison with actual demand. In general, the trend of these forecasts has shown increasing accuracy, and the variation from the actual for the year 1938 will be considerably less than 1 percent.

When actual changes in gasoline stocks are greater or less than anticipated, cumulative corrections must be applied in subsequent forecasts for progress toward proper stock equilibrium. Excessive runs to stills in one period must be compensated by lower estimated runs than originally anticipated in later forecasts. This factor involves duplication of the estimates not only of gasoline stock reductions but also in runs to stills and total market demand for crude.

Methods Used in Forecasting Demand

A report on the forecast methods used by the Bureau of Mines was made to a special committee of the Interstate Oil Compact Commission and was published in the "Transcript of Proceedings of the Compact Meeting" at Colorado Springs July 29, 1938.

The first major step in the Bureau's forecast involves estimating the probable domestic demand for motor fuel (not including heavier oils like Diesel oil) by all agencies; that is, by automobiles, stationary engines, motor boats, cleaning establishments, etc. Of these, the automotive consumption is by far the most important, comprising about 89 percent of the total. The national demand for automotive gasoline can be forecast with a comparatively high degree of accuracy for short periods because of the stability, or absence of market fluctuations, in the number of motor vehicles in use and the reliability of the trend of gasoline consumption per motor vehicle. The nonautomotive uses of gasoline comprise such a small and unvaried proportion of the total demand that they are included in the calculation of the gasoline demand per motor vehicle. The number of motor vehicles in use is calculated monthly, and the figure is divided into the daily average motor fuel demand to obtain the daily average motor fuel demand per motor vehicle. The individual monthly statistics from this calculation are then correlated with a monthly business index to obtain an estimating equation for forecasting motor fuel demand. The estimated average gasoline consumption per motor vehicle multiplied by the total number of motor vehicles in use gives an estimate of the total domestic demand for gasoline in the United States. Motor fuel exports, added to domestic demand, give the estimate for total demand. The gasoline export estimates are based on forecasts received by the Bureau of Mines from the principal exporters of the country and on statistics of past exports compiled by the Bureau of Foreign and Domestic Commerce.

The next major step in the Bureau's forecast involves forecasts of seasonal changes in gasoline stocks. Increasing winter accumulations of gasoline stocks, with subsequent necessary summer liquidation, are due to the greater relative demand for heating distillates in the fall and winter months. Since the peak monthly yield of gas oil and distillate fuel oils from crude has not greatly exceeded 14 per cent, it requires the running of at least 7 million barrels of crude oil to produce 1 million barrels of distillate fuels, and this, in turn, involves the production of a minimum of about 3 million barrels of gasoline. Unless stocks of heating oils are accumulated in advance a large winter accumulation of excess gasoline is unavoidable, but is subject to extreme monthly variation, owing to unusually mild or unexpectedly cold weather. As a part of its monthly forecast, the Bureau of Mines must set up an estimated high point in gasoline stock accumulation, generally as of March 31, and an estimated low point, generally as of October 31. The estimated seasonal increase in gasoline stocks in the months from November to March, inclusive, is based on the normal demand for distillate fuel oils, to be met by liquidation of available distillate stock and from necessary new production at probable yields from crude. Unusually cold weather results in an unexpected increase in demand and causes larger refinery runs and greater gasoline stock increases. An estimated seasonal program of decrease in gasoline stocks, from April to October, inclusive, must be set up with an objective which will reduce such stocks to a reasonably normal position. If the original estimated decreases fail to materialize for several months, additional cumulative estimates of reduction must be made for later months. Considerable further research is essential for the determination of the proper ratio of gasoline stock levels to increase in gasoline demand.

After estimating total motor fuel demand and the necessary changes in gasoline stocks, the amount of required new production from all sources is indicated. In order to determine the amount of straight run and cracked gasoline to be produced from crude petroleum, the estimated sales of benzol and natural gasoline direct from producer to consumer are first deducted, giving a remainder representing required refinery output. The further deduction of natural gasoline blended at the refinery gives the estimated amount of refinery gasoline to be produced from crude. The yield of gasoline from crude oil is estimated on the basis of seasonal factors in relation to the required output of other products. The necessary amount of crude petroleum to be run to stills can now be computed. Deduction of the estimated runs of foreign crude gives the amount of domestic crude required for refinery operations.

The next step is to determine the refinery demand for crude oil by refinery districts. The total national motor fuel demand is allocated to the market areas associated with the refinery districts, on the basis of consumption data derived from the State gasoline tax figures. The gasoline supply for each district is obtained from five sources, namely, from stocks, from sales of benzol and natural gasoline direct from producers to consumers, from natural gasoline blended at refineries, from receipts from other districts, and from crude oil refined within the district. Stock changes are based on the normal relationship in each district between inventories and shipments. Inasmuch as the fifth source—crude runs to stills—comprises the major portion of the allocations, the general procedure involves the estimation of data from the other four sources and their deduction from the required supply. These operations complete the estimates as to the gasoline production required from crude refined in each district.

The determination of the crude required by refineries in each district involves the review of the district record of operations to determine the estimated gasoline yield from crude oil and its application to the figure of gasoline production obtained above. The next step covers the allowance for crude imports and involves the setting up of estimates for probable runs of foreign crude and the subtraction of these data from total crude-oil requirements at refineries. The domestic crude requirement in each district is then broken down proportionately among the producing States which have supplied the refinery needs of that particular district in the past, on the basis of established channels of movement between districts. The summation of these data gives a break-down of total refinery demand for domestic crude by States of origin. The last step involves the estimate of probable crude exports, direct uses as fuel, and losses by States; and the addition of these estimates to the data of refinery demand by States gives the total market demand for domestic crude oil by States of origin.

In general, all of the estimates outlined above are based on the trends shown by the most recent official statistics and sources of industry information.

The method just described gives the final figure for the national market demand for domestic crude. The figures for distribution among the States, however, are subject to further weighting as to their share of this total, since complete information is not available on certain phases of interdistrict movements and refinery operations. The shares of the States under the above method are given a weighting of 50 percent in the final forecast. The demand for crude by States can be determined by another method, namely, the State production of crude plus or minus changes in crude stocks of State origin. The trend of these demand figures is determined on a percentage basis and the percentages are applied to the estimated total market demand for crude to produce distribution figures by States that are given a weight of 25 percent in the final forecast. As a further factor of stability, the percentages of market demand by States, finally worked out in the previous month's forecast, are applied to the new forecast of total demand and the resulting distribution is given a 25-percent weighing in the final forecast.

PART FOUR—SECTION IV
REGULATORY MEASURES IN THE COAL INDUSTRY

CHAPTER 1.—RECENT REGULATION OF THE BITUMINOUS COAL INDUSTRY IN THE UNITED STATES

By Wilbert G. Fritz*

Proposals for Regulation

The Federal Government undertook regulation of the bituminous-coal industry on an emergency basis during the World War. The Food and Fuel Control Act, passed August 10, 1917, provided for control of prices, production, distribution, and storage of coal. This emergency regulation was abandoned after the close of hostilities, but wartime conditions so disrupted the industry that an acute shortage of coal developed in 1920. The business depression of 1921 resulted in a rapid decline of both production and prices. Unemployment and pressure on wage rates were further consequences. Prolonged strikes in 1922 led to the creation of the United States Coal Commission to investigate the industry. The Commission issued a voluminous report of findings and recommendations, which it referred to the Senate Committee on Mines and Mining in December 1923. Although the Commission was only a fact-finding and advisory body, its investigation marked a turning point in attitude toward the bituminous-coal industry. In subsequent years there has been a growing conviction that the coal problem is not one of temporary recession but instead one that requires basic readjustments. Since the actual publication of the report of the Commission in 1925 numerous attempts have been made to regulate the industry. The chief lines of attack have been as follows:

1. Self-regulation by the industry.
2. A dual system of regulation established under the National Recovery Administration in which codes were established largely by the industry but enforced by the Federal Government.
3. Regulation of the industry by the Federal Government under acts passed in 1935 and 1937.

The first important effort after the war period to regulate the bituminous-coal industry was through Appalachian Coals, Inc., a marketing agency, established in 1932. Prior to that year several concrete proposals for self-regulation had been suggested. None of these earlier major schemes succeeded, but some of the plans were seriously considered. In southern West Virginia three proposals for the organization of sales agencies or amalgamations were put forward between 1925 and 1928. These schemes were the predecessors of Appalachian Coals, Inc., the last of them resembling very closely the organization actually adopted. Had it not been for doubts in regard to validity under the antitrust laws the 1928 plan probably would have become an actuality.

The United Mine Workers of America has been the chief sponsor of governmental control plans. This organization has been active from time to time in suggesting plans for general control of the industry. In the year following the World War, nationalization of the industry was favored by the union, but this policy has not been recommended by the organization in recent years.

In 1927 widespread strikes in the northern fields led to a revival of interest in control. The union was losing power rapidly and was seeking ways to reestablish itself. In 1928 and 1932, bills were introduced in Congress providing for control of the industry under the plan suggested by the United Mine Workers.[1] The basic proposals included in the bills were inspired by the *Report of the United States Coal Commission*. This report recommended:

1. That the Interstate Commerce Commission be made responsible for supervision of the coal mining industry and that it give special attention to the question of uneconomic freight rates and railroad car shortages.
2. That a special division be created in the Interstate Commerce Commission for the purpose of regulating the coal industry. The Coal Commission was averse to the establishment of a new and unattached governmental agency and felt that, because regulation of the coal industry would be largely a matter of regulating interstate commerce, the Interstate Commerce Commission was the logical regulatory body. Among the various duties to be assigned were the distribution of coal in times of national shortage, such as existed in 1922, and the promotion of consolidations. The special division, furthermore, would have the right to ob-

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[1] S. 4490 in 1928 and S. 2935 in 1932.

tain all needed information either from original sources or from bureaus collecting it.

3. That attention be given by the special division to prevent the further development of excess capacity in the coal industry. This control should be exercised through the licensing of mines shipping coal into interstate commerce and by limiting the extension of railroad facilities to new mines.

These recommendations were colored by the post-war situation, and more emphasis was therefore placed on the prevention of shortage than on the control of excessive capacity. The licensing proposal suggested by the Coal Commission was used by the United Mine Workers as the basis for the bills introduced in Congress in 1928 and 1932. Under these bills, however, the licensing authority was not to be a division of the Interstate Commerce Commission but a separately appointed Federal coal commission. It was the intention to impose satisfactory labor standards on the operators, especially with regard to wages and hours.

The 1928 bill provided for organization by the industry of marketing agencies and amalgamations of producers. Companies could enter into such arrangements by procuring licenses from the Federal commission. It was expected that this commission would impose satisfactory labor standards through the provisions of the licenses. The commission could, if necessary, fix maximum prices, but no provision was included for fixing minimum prices.

The 1932 bill (Davis-Kelly bill) was based on the same general idea and was designed to secure for the mine workers the right of collective bargaining through the licensing and regulation of coal operators engaged in shipping coal into interstate commerce. This bill contained provisions for marketing agencies but not for amalgamations of coal companies.

Neither the 1928 nor the 1932 bill got beyond the Senate committee. That the proposed legislation was not adopted was due in large measure to the fact that conditions in the industry had changed markedly after the report of the Coal Commission was presented. There was no longer danger of acute shortage. The period of extensive strikes had passed, and wage rates had been restored. The chief problem was the existence of a large surplus producing capacity, most of which had accumulated since the war, and of ruinously low prices. Operators were strongly opposed to the two bills. Although their opposition had softened somewhat by 1932, most of them continued to favor self-regulation. Some of them preferred to be let alone, in the hope that conditions would improve without intervention.

Another bill providing for the regulation of the bituminous coal industry was also under consideration in 1932.[2] It was introduced by Representative David Lewis and was based on part I of the British Coal Mines Act of 1930. The bill had little support at first, but toward the end of the hearings it was more favorably received by the industry because of the provision for a measure of self-regulation. Hearings were discontinued abruptly when the National Industrial Recovery Act was passed.

Control by Appalachian Coals, Inc.

Coal operators long have considered governmental control of production and other governmental intervention in industry as being outside the range of activities permitted under the Constitution. It is natural, therefore, that the first experiment sponsored by operators for the control of the industry should be a private organization of operators rather than some form of governmental supervision and regulation. In February 1931 a conference of coal operators was held in Washington to discuss the critical situation of the industry and to formulate a plan of action for its relief. The upshot of the meeting was a report advocating an organization of operators along the lines actually followed in the organization of Appalachian Coals, Inc. The plan formulated at the Washington meeting led to the launching in 1932 of Appalachian Coals, Inc., a sales agency intended to cover the high-volatile coal fields of southern West Virginia, Virginia, eastern Kentucky, and northeastern Tennessee. Under the plan of organization, operators were invited to become shareholders in the corporation and to enter into a contract appointing the corporation as exclusive sales agent for the producers. This exclusive agency arrangement was adopted to establish a close legal control by Appalachian Coals over its membership, but the central agency did not actually operate as a selling organization. Sales were made through subagencies directly representing the coal companies. In addition to the primary contract, each member contracted with a subagency for the actual sale of coal. This third organization, also a party to the original Appalachian Coals contract, was often the sales organization or division of the producing company.

The primary function of Appalachian Coals was control of minimum prices. Under the provisions of the contract, classifications and price schedules were prepared covering all kinds and sizes of coal produced by member companies. This price list, it should be observed, became the prototype of later price schedules established for the bituminous-coal industry. A factor working against the successful control of price was the fact that membership in Appalachian Coals was voluntary, and for this reason it was impossible to provide stringent enforcement. Producers dissatisfied with the classification of their coals, however, had the right of appeal to a board of arbitration.

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[2] H. R. 9924.

With respect to production control under Appalachian Coals, the original contract of 1932 provided that the selling agency should use its best efforts to sell all the coal produced, and that when the demand became insufficient to absorb the output of all members, participation should be determined as nearly as possible by the ratio of their railroad-car allotments. When the contract was renewed in 1935, the corporation was required to keep average operating time at a uniform level, based on the car-allotment ratings. The 1938 contract, however, omitted all reference to operating time or car allotments.

The first year of the life of Appalachian Coals was spent in establishing its validity under the law. An injunction against the corporation was granted in 1932 by the United States District Court at Asheville, N. C., on the ground that the plan violated the Federal antitrust laws. In March 1933 this ruling by the district court was reversed by the United States Supreme Court.[3] The Court warned the corporation, nevertheless, that its decision did not mean that the Government would be precluded from taking necessary steps, should the plan under actual operation unduly restrict interstate commerce.

The Bituminous Coal Code Under the N. R. A.

Since the time of its organization in 1932, Appalachian Coals has held the center of the stage only for brief periods in 1933, 1935, 1936, and the early part of 1937. During these limited periods of activity the corporation served as a stopgap between the various governmental experiments in the field of regulation. The major events in the regulation of bituminous coal from the early part of 1933 to the present are as follows:

March 1933, favorable decision of the Supreme Court in the *Appalachian Coals* case.

October 1933, inauguration of the Bituminous Coal Code under the N. R. A.

May 1935, invalidation of the National Industrial Recovery Act.

August 1935, adoption of the Bituminous Coal Conservation Act of 1935.

May 1936, the coal act of the previous year declared invalid by the Supreme Court.

April 1937, the Bituminous Coal Act of 1937 became law.

February 1938, withdrawal of coal-price schedules established under the coal act.

The first extensive peacetime regulation of the bituminous coal industry under Federal auspices occurred under the National Industrial Recovery Act, which, as its name implies, was to be used as one of the most important weapons in an attack on the business depression, and was an "enabling" act of extremely general character. Under its provisions detailed regulatory schemes relating to various industries were contemplated, and it was under this act that the coal-mining industry, as well as industries dependent on coal, adopted codes of "fair competition." Coal operators were required to abide by a code written to comply with the general provisions of the act. The Code of Fair Competition for the Bituminous Coal Industry called for maintenance of minimum prices and elimination of unfair competitive practices. The act gave to the code the force of law and made it binding on all operators. It required operators to observe the minimum-wage and maximum-hour provisions of the code, to bargain with duly elected representatives of employees, and to refrain from interfering with the free choice of representatives by the employees. These provisions had an important effect, resulting in a large-scale movement toward trade-union organization. Advantages to the industry included establishment of effective organizations for eliminating destructive wage and price cutting. Administrative codes of the various industries were in the hands of the industries themselves, under the general supervision of the National Recovery Administration. Although the code imposed self-regulation on the industry instead of Federal regulation, the power of the Federal Government was placed behind the industry to enforce compliance. The code became effective in October 1933 and remained in force until May 1935, when the *Schechter* case decision by the Supreme Court, invalidating the Recovery Act,[4] forced abandonment of the code.

In the bituminous coal industry, lasting achievements under the National Recovery Administration Code consisted of almost complete unionization of the miners and stabilization of interdistrict wage differentials, changes that have continued up to the present time. Early in 1933 the strength of the United Mine Workers of America was the lowest in several decades. Only in Illinois and Indiana was there any considerable degree of union organization remaining. In the Appalachian region, except for southern Ohio, the union had collapsed. One of the first results of the passage of the National Industrial Recovery Act was rapid rehabilitation of labor organization. In thel atter part of 1933 the union was able to negotiate with the operators on a national basis, and the eventual result was that 95 percent of the miners became members of the leading union. Negotiations by the union on an interstate basis put an end to competitive wage cutting between districts.

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[3] *Appalachian Coals, Inc. v. U. S.*, 288 U. S. 344 (1933).

[4] 295 U. S. 495 (1935).

Other provisions favoring labor included the establishment of a National Bituminous Coal Labor Board and numerous miscellaneous regulations, such as those prohibiting compulsory trading in company stores.

One of the basic principles of the N. R. A. was the establishment of fair competition. Competitive price-cutting and "chiseling" of prices, considered the main reasons for economic disruption, were the more obvious evils of the industry. Naturally, the framers of the code set out to deal with the situation by means of price control.

Committees of operators known as code authorities were set up in each division. There was also a national organization of operators known as the National Bituminous Coal Industrial Board, but on which labor and the public also were represented. Original provisions regarding price-fixing were general and extremely vague, but these were replaced in January 1935 by more detailed price structures. In fixing prices, reference was not made to the cost of production but rather to the classification of coal; that is, variations in prices of particular coals were to be made according to the characteristics and uses of the coal.

In assessing the achievements of the coal industry under the N. R. A., prominence must be given to results in the sphere of labor. Within a few months the miners achieved almost complete unionization, and in addition wage and hour standards were materially heightened. Prices for coal were also raised. The average realization per ton of bituminous coal at the mine increased from $1.54 in 1931 to $1.75 in 1934 and $1.77 in 1935. Price increases accounted in large part for the transformation from a large deficit in 1933 to almost no deficit in 1934. Although evasion of the minimum prices became increasingly serious, it appears certain that the former losses of the industry were greatly reduced. The N. R. A. price-fixing experiment has served as a basis for subsequent attempts to rehabilitate the industry by means of the control of minimum prices.

In May 1935 the United States Supreme Court by its decision in the *Schechter* case declared the National Industrial Recovery Act to be unconstitutional, mainly on the grounds that it provided for delegation of legislative power to the President and that it permitted Federal interference in matters not directly affecting interstate commerce. Even before this decision, however, the N. R. A. codes in various industries had been collapsing, owing to evasion of the pricing provisions and to a growing belief that the law would be held invalid. The coal industry was among those conspicuous in evasion of its code.

The Bituminous Coal Conservation Act of 1935

Before the decision of the Court on the N. R. A. a bill was under consideration by a committee of the Senate to renew regulation of the bituminous-coal industry, and almost immediately after the decision the bill was introduced. Largely because of price evasion under the N. R. A. code, the merits of production control were discussed at length during the hearings on the bill. Sponsors of production control contended that control of minimum prices had been difficult to administer and that the results desired could be obtained more effectively and easily by control of output. In fact, belief was expressed that, with adequate control of production, there would be no need of control of minimum prices because, on the one hand, prices would tend to rise as production was restricted, and, on the other hand, excessive prices could be prevented by expansion of output on short notice. The existence of a large excess capacity would insure prompt acceleration of output in the event of expanded demand.

The first bill presented to the Senate was sponsored and also drafted in large part by the United Mine Workers of America, after the refusal of operators to collaborate. This bill, which was given considerable thought by the Senate Committee on Interstate Commerce in February and March 1935, dealt with: (1) a plan of production control in which district and mine output quotas would be allocated by national and district boards of operators, (2) establishment of minimum prices based on the cost of production in each designated price area, (3) stabilization of the underlying wage structure through compliance with wages and hours schedules agreed upon by a two-thirds majority of operators, (4) the elimination of surplus capacity through the purchase of coal deposits by the Federal Government.

A large group of operators, in particular the owners of captive mines, remained adamant against Federal legislation in any form that would result in governmental control of the industry. Other groups, however, claiming 60 percent of the tonnage, collaborated with the miners and supported the bill with some modifications.

In final form, the bill was changed by the deletion of the production-control provision and of the section regarding Federal purchase of coal deposits and by the insertion of provisions for creating a consumers' counsel. The Bituminous Coal Conservation Act of 1935 (commonly referred to as the Guffey-Snyder Coal Act or the "little N. R. A.") became law in August 1935 and thereby took the place of the abandoned code.

The act was an important phase of the development of a regulatory program for bituminous-coal industry. It created a National Bituminous Coal Commission of five members in the Department of the Interior to administer the provisions of the law. To enforce compliance, a tax of 15 percent of the sales value of the coal at the mine was levied, with the provision that a refund of 90 percent of the tax should be made to operators complying with the terms of the code. The act required the organization of 23 district boards of coal operators who should determine minimum prices for coal according to a prescribed formula.[5] Such prices were subject to approval by the Coal Commission. Maximum prices could be set by the Commission if it deemed such action necessary to protect the public interest.

A wage agreement negotiated in any district by producers of two-thirds of the tonnage and representatives of a majority of the workers was binding on all producers in the district. Maximum daily and weekly hours agreed on by employers producing two-thirds of the national tonnage and by representatives of a majority of the workers were likewise binding on all code members. Collective bargaining by representatives of the miners' own choosing was explicitly protected. Employees were guaranteed the right of peaceable assemblage, were permitted to select their own checkweighmen, and were protected against any compulsion that they live in company houses or trade at the store of the employer. A Bituminous Coal Labor Board of three members was created, one member a representative of the employers, one a representative of the organized employees, and one (the chairman) an impartial person with neither financial interest in the industry nor connection with an organization of the employees. The Labor Board had authority to hold elections, to determine the choice of representatives of the employees, and to adjudicate labor disputes arising under the provisions of the act.

Consumers were to be represented before the Coal Commission through the Consumers' Counsel, who had the right to be heard on all matters affecting the interest of consumers. He could require the Commission to supply information and to conduct investigations which he deemed necessary.

The chief burden of administration was assigned to the 23 district boards, each of which was to have not less than 3 nor more than 17 members, one being a labor representative and the remainder representatives of producers. No doubt the chief interest of the board was the fixing of minimum prices. The act did not provide for the direct administration of working conditions and wage rates. It depended on action by unions to promote the interests of the laborers, although, as in the N. R. A. Code, it guaranteed the right of collective bargaining and protection against compulsion in connection with company unions, company houses, and company stores. As the result of a writ brought by the Carter Coal Co. and others, the Supreme Court on May 18, 1936, declared, by a five-to-four decision, the act's labor provisions an invasion of State rights and thus beyond the constitutional powers of the Federal Government.[6] Although the Court reserved judgment on the validity of the price-fixing and unfair-trade provisions, and although the act had a separation clause stating that if any provision was held invalid the remainder would be unaffected, the Court held the entire act as a unit invalid on the ground that the provisions with respect to price fixing and determination of trade practices in interstate trade were inextricably linked with the invalid labor provisions.

The act, during its existence, strengthened the position of the union to such an extent that the miners were in a position to bargain with the operators. The success of such negotiations depended, in part, on the operators' having sufficient stability to meet the demands of the union. Consequently, labor groups were willing to support reenactment of legislation providing for price-fixing and regulation of trade practices, even though the Court's decision of May 18, 1936, precluded Federal regulation of wages and hours on the basis specified in the 1935 act.[7]

The Bituminous Coal Act of 1937

After the 1936 decision of the Supreme Court declaring the first Guffey Act unconstitutional, steps were taken at once to amend the original law and to introduce it into Congress as a new bill. Even though the House of Representatives passed the bill in 1936, and even though there was only feeble resistance generally to reenactment, Congress adjourned before the Senate took action. The bill, however, was given first position on the Senate calendar when Congress reconvened, and it soon received legislative approval. The Bituminous Coal Act of 1937 (commonly known as the Guffey-Vinson Coal Act) became effective on April 26, 1937. This act aimed primarily at a restoration of price fixing for the industry. Provisions in the earlier act with regard to labor were not repeated, but in their place was inserted a declaration of labor policy. The act has a projected life of 4 years from its effective date.

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[5] Weighted average cost of production in the minimum price area to which, under the act, a district belonged.

[6] 298 U. S. 238 (1936).

[7] Later decisions by the Supreme Court, of course, take a broader view of the regulatory power.

Objection had been made to the N. R. A. Coal Code and to the 1935 act that regulation was vested in district boards representing private industry.[8] Since the constitutionality of this provision was questioned, the 1937 act vested in the National Bituminous Coal Commission, representing the Government, the power to determine and make effective minimum prices for coal, with the district boards of operators limited to proposal of minimum prices.

Another feature of the new act having a direct bearing on its legality is that expenses incurred under it are not linked with the taxes levied on coal companies. Expenses are met from general appropriations made from the Federal Treasury. On the other hand, all bituminous-coal producers are required to pay an excise tax to the Treasury of 1 cent per net ton on all output except that sold directly or indirectly to governmental bodies for their own use. In addition, a tax of 19½ percent is levied on the mine price of coal disposed of by sale at the mine or on the fair-market value of coal disposed of otherwise; the purpose of this tax is enforcement of the act instead of revenue, and the tax is not collected from code members in good standing. Producers certified by the Coal Commission to the Commissioner of Internal Revenue as code members complying with rules and regulations are exempt from the 19½-percent tax. If intrastate companies are declared not subject to the jurisdiction of the Commission, they also are beyond the reach of the tax. In spite of the apparent separation of the administration expenses and the taxes collected, it is evident that self-support was a consideration in the levy of the taxes.[9] Owing to the almost universal exemption from payment anticipated for the *ad valorem* tax, the specific tax of 1 cent per ton becomes the means of obtaining the revenue necessary to offset the expenses incurred. Collections from the specific tax would have been about $4,000,000 in 1936. This amount would more than meet the cost of administration.[10]

Members complying with the code are exempt from the Federal antitrust laws. The Bituminous Coal Code is written into the act as section 4. The code provides for 23 district boards, each to consist of not less than three nor more than 17 members. One member is to be selected by the organization of employees representing the preponderant number in the district. Of the remaining members, one-half are to be chosen by a majority vote of the number of members and one-half by votes cast in proportion to annual tonnage of output. Members of the district boards serve as such without compensation, but they may be reimbursed for their reasonable expenses. Expenses of administering the code by the respective boards are borne by the code members on a tonnage basis. Allocation of voting strength, in part, and of financial support, entirely, on a tonnage basis, of course, gives large producers an advantage. Some check to this concentration is afforded by the provision that not more than one officer or employee of any code member within a district shall be a member of the district board.

The National Bituminous Coal Commission is composed of seven members[11] appointed by the President, by and with the advice and consent of the Senate, for a maximum term of 4 years, and is in the Department of the Interior. Members are not permitted to have any financial interest directly or indirectly in the mining, transportation, or sale of coal (including nonbituminous coal), oil, or gas, in the generation, transmission, or sale of hydroelectric power, or in the manufacture of equipment for coal, oil, gas, or for the use of hydroelectric power. They are not permitted to engage actively in any outside business, vocation, or employment. Two members of the Commission are required to have been experienced bituminous-coal miners and two to have had experience as producers. The remaining three members need not have either of these qualifications. Although the Commission is required to maintain its principal office in Washington, D. C., offices elsewhere may be established. The time and place of meetings are to be determined by a majority vote of the members of the Commission.[12]

The Commission has numerous duties with regard to collection and reporting of information. It is obligated to make a full report of its activities annually to the Secretary of the Interior for transmission to Congress. Each of the districts has a statistical bureau, an agency of the Commission directed to serve as confidential custodian of reports submitted by code members.[13] Code members are required to report to the statistical bureaus all spot orders, to file copies of sales contracts, invoices, and credit memoranda, and to submit such other information concerning the preparation, cost, sale, and distribution of coal as the Commission shall direct.

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[8] *Hearings before a subcommittee of the Committee on Interstate Commerce, United States Senate*, 75th Cong., first sess., on S. 1, p. 13.

[9] *Ibid.*, p. 19. The Senate subcommittee considered a tax of one-half of 1 percent on the price of the coal instead of the tax of 1 cent per ton.

[10] *Ibid.*

[11] Under the 1935 act the Commission had five members. A Commission of seven members was organized on May 17, 1937. Since the resignation on April 6, 1938, of the original chairman it has functioned with six members.

[12] In the hearings on the Senate bill, there had been strong agitation for locating the office in or near the coal fields, but this proposal met resistance from many Senators who feared invalidation of the measure if the Commission were not patently an instrument of the Government. The provision adopted was a compromise.

[13] Under the 1935 act statistical bureaus were a part of the district organization. District boards may maintain separate statistical organizations, but information gathered by them has no official standing with the Commission. See *Hearings, op. cit.*, p. 14.

The Commission may prescribe a uniform system of accounting for costs, wages, operations, sales, profits, losses, and other items considered in the administration of the act. Furthermore, no person is excused from testifying or producing records on the ground that such action may tend to incriminate him or subject him to a penalty or forfeiture. Findings of the Commission as to the facts, if supported by substantial evidence, are to be considered conclusive.

Undoubtedly the outstanding function of the Commission is the fixing of fair minimum prices for bituminous coal. Under the act each district board is to propose minimum prices free on board at the mines, such prices to yield a return per net ton equal as nearly as possible to the weighted average cost in groups of mining districts designated as minimum price areas. The Commission may approve, disapprove, or modify the minimum prices proposed by the district boards.[14] Total cost used in arriving at the price quotations is specified to include the cost of labor, supplies, power, taxes, insurance, workmen's compensation, royalties, depreciation and depletion (as determined by the Bureau of Internal Revenue in the computation of the Federal income tax), and all other direct expenses of production, as well as association dues, assessments for district board expenses, costs of administration, and reasonable costs of selling. Only the lower-than-average-cost producers in each minimum price area will have a residual income properly termed profits if sales are made at the established minimum level.

The problem of pricing, however, is not so simple as the cost formula suggests. Average cost is not the only factor to be considered. The act further specifies that minimum prices "shall reflect, as nearly as possible, the relative market value of the various kinds, qualities, and sizes of coal, shall be just and equitable as between producers within the district, and shall have due regard for the interests of the consuming public." No provision is made for priority of claim in the event of a conflict of interest. Moreover, there is superimposed on these price requirements the further requirement of coordination in "common consuming markets upon a fair competitive basis." The coordination is to take into account such factors as classification of the coal, relative market values of the coal at the points of delivery (consideration being given to "values as to uses, seasonal demand, transportation methods and charges, and their effect upon a reasonable opportunity to compete on a fair basis"), competition between coal and other forms of fuel and energy, and existing fair competitive opportunities. Coordinated prices, it is specified, shall not in any district reduce or increase the return per net ton on all bituminous coal produced to cause a deviation from the minimum price more than is necessary for the coordination. The Commission is empowered to prescribe reasonable maximum discounts to distributors who resell the coal in not less than cargo or railroad carload lots and to require such persons to observe resale prices and marketing rules and practices established under the code. Distributors, even though they do not engage in coal production, therefore, are subject to considerable regulation, and, owing to the power of the Commission to coordinate minimum prices in consumer markets, it sets the minimum purchase price for retail dealers.[15] Distributors and dealers are not represented directly on either the Commission or the district boards, but their complaints have been presented by the Consumers' Counsel, who has the power to compel a hearing by the Commission on valid complaints.[16]

It is the duty of the Consumers' Counsel to appear in the interest of the consuming public before the Commission and to conduct independent investigations of the coal industry and of the administration of the act which will enable him properly to represent the consuming public. He may require the Commission to submit to him any information at its command. He is authorized to make such expenditures as are necessary for the performance of the duties vested in him. The Counsel is appointed by the President, by and with the advice and consent of the Senate, and he may not have an interest in the coal industry or related industries, a requirement exactly the same as that provided for members of the Commission.

When the Commission deems it necessary to protect the consumers against unreasonably high prices for bituminous coal, it may establish maximum prices free on board transportation facilities for coal in any district, but such maximum prices must reflect a uniform excess above the existing minimum prices so that, in the aggregate, the maximum prices shall yield a reasonable return above the weighted average cost of the district.[17] Despite the power of the Commission to fix both the minimum and the maximum prices, it cannot close the gap between the two levels to the end that it sets the exact price. The Commission has no legal authority for preventing increases above the minimum unless they yield a return in excess of what is ascertained to be reasonable. Should the maximum prices be contested, the Commission will be confronted with a valuation problem similar to that of the Interstate Commerce Commission. Domination of the market by a group of producers, however, is only a remote possibility. The real problem is ruinously low prices. Interdistrict competition in the industry and competition with other fuels keep prices low. Any producer may slash prices even below the minimum set by the Commission if he pays the penalty tax of 19½ percent. Undue control of the market also may be held in check. The Commission may refuse to approve membership of producers in cooperative selling agencies, on the ground that such agencies will unreasonably restrict the supply of coal in interstate commerce, will prevent the public from receiving coal at fair and reasonable prices, will operate against the public interest, or on the ground that they do not meet the marketing regulations established by the Commission. Another deterrent to large price increases—aside from the normal deterrents in this highly competitive industry—is the possible exemption of intrastate producers from membership in the Code. Proponents of Federal regulation have contended that substantially all intrastate transactions in bituminous coal directly affect interstate commerce in such coal, and that, therefore, they are subject to the terms of the regulatory act.[18] To determine the extent of interdependence of interstate and intrastate commerce in bituminous coal, the Commission has conducted investigations and held public hearings in 23 States. In North Carolina intrastate sales were found to have no direct effect on interstate commerce. In all other States where the question has thus far been decided, the intrastate shipments have been found to be subject to regulation, and appropriate orders have been entered. The law provides, however, that an individual producer believing that his business does not affect interstate commerce may apply for exemption from these orders. Liberal grants of exemption to intrastate producers, of course, would tend to defeat the purposes of the act. On the other hand, even limited exemption is a restraining influence on price manipulation. In sum, it does not appear probable that the power to invoke maximum prices will have to be utilized in the near future.

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[14] Under the act, sales contracts entered into since June 16, 1933, the date of enactment of the National Industrial Recovery Act, are revoked if they call for prices below the minimum or above the maximum approved by the Commission.

[15] Wholesale discounts, commissions, rebates, or dividends may be granted to farmers' cooperatives. On the other hand, allowances to urban cooperatives are not sanctioned.

[16] The status of complaints of retail dealers is obscure under the act. The Consumers' Counsel, however, has interpreted his function to cover selling activities, including cooperative marketing. Such interpretation appears to be not only desirable but necessary. (See *Annual Report, Fiscal Year 1938*, Consumers' Counsel, pp. 12 and 13.)

[17] The provision of the act for maximum prices (sec. 4, pt. II, subsec. (c)) is ambiguous and needs revision. On the one hand, it embraces the principle of fair return above average cost for the district, and, on the other, it specifies that no maximum price shall be established for any mine that does not yield a fair return on the fair value of the property. Obviously the Commisison cannot fix prices on the basis of average cost and at the same time allow a fair return even to the highest cost producers.

Provision is made for cooperation between the Nation Bituminous Coal Commission and the Interstate Commerce Commission. To safeguard the interests of those concerned in the mining, transportation, selling, and consumption of coal, the Coal Commission and the office of Consumers' Counsel of the Commission are vested with authority to make complaint to the Interstate Commerce Commission with respect to rates, charges, tariffs, and practices relating to the transportation of coal and to pursue the grievances. Conversely, the Interstate Commerce Commission is authorized to avail itself of the cooperation, services, records, and facilities of the Coal Commission.

Among its many powers, the Commission is authorized to investigate methods of increasing the uses of coal, problems of importation, exportation, economic operation of the mines. conservation of coal resources, mine safety, lowering of marketing costs, and the need of production control. Findings are to be reported to the Secretary of the Interior for transmission to Congress.

In this connection it should be observed that there is danger of needless duplication of work with other branches of the Federal Government. The Bureau of Mines, in particular, was created to conduct inquiries and to undertake scientific and technologic investigations.[19] It has spent years in developing a competent personnel and in establishing necessary cooperation with operators. The distinction to be drawn is that the National Bituminous Coal Commission is a regulatory body and should function where rules and regulations of conduct are required, whereas the work of the Bureau of Mines and other similar organizations is primarily of a research character and involves only voluntary cooperation with the industry.

Unlike the earlier Coal Act, the new act has no provisions for the regulation of labor relations, these provisions being excluded because of the invalidation of the 1935 act by the Supreme Court in the *Carter Coal* case of May 18, 1936. Instead, there is included as section 9 (a) of the new act a declaration of public policy with regard to labor, but the declaration adds nothing to the National Labor Relations Act already declared constitutional by the Court, a law applicable to the bituminous coal industry as well as to other industries. The National Labor Relations Act practically reestablishes for coal miners what was lost in the *Carter Coal* case. Accordingly organized labor has been quite content to accept the Coal Act without provision for the legal protection of its own welfare. Price-fixing features, it felt, would strengthen labor's position through strengthening the economic structure of the industry.

There are three means by which the Coal Act many be enforced: (1) The Commission may, after proper hearings, order a member to cease and desist from violations and, on failure of the member to comply with such order, may apply to a circuit court of appeals for enforcement; (2) the Commission may, after a hearing and 30 days' written notice to the member, revoke membership in the code and, therewith, the right to exemption from the 19½-percent tax on the price of coal; (3) any code member sustaining injury from another member may sue therefor in any court of competent jurisdiction where the defendant resides or does business and, on proper proof, recover threefold damages and the cost of the suit, including a reasonable attorney's fee. Any producer whose membership has been revoked may be reinstated by the Commission on payment to the United States of double the amount of the 19½-percent tax on the coal sold.

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[18] *Federal Register*, vol. 2, No. 119, June 22, 1937, p. 1266.

[19] See especially sec. 2 of the amendment passed February 25, 1913, to "An Act to Establish in the Department of the Interior a Bureau of Mines," the original act having been approved May 16, 1910.

The Initial Experience Under the 1937 Act

The Bituminous Coal Code provided for by section 4 was promulgated by the Commission on June 21, 1937, and on the same date, by Executive Order, taxes authorized by section 3 of the act became effective.[20] Support of the 1937 act was better at the start than that given the 1935 act. On November 19, 1938, there were 11,909 code members, representing about 95 percent of the output for 1936, but taking into account exemptions claimed on the ground that the coal does not move in commercial markets, the membership includes all but a negligible percentage of the commercial production.

Producers' boards and statistical bureaus were established in 22 of the 23 districts in bituminous coal producing areas of the country. No boards or bureaus have been established in the district covering North and South Dakota because the coal is below rank "bituminous coal" as defined in section 17 of the act.

Section 4, part II, designates three steps leading to establishment of prices:

1. Determination of weighted average cost of production in the minimum price areas named in the act.
2. District boards propose minimum prices and marketing rules and regulations. The Commission approves or modifies the prices.
3. District boards coordinate the prices in common consuming markets as directed in the act.

Certain eastern boards were unable to complete the coordination within the allotted time and the Commission took over the work pursuant to section 6 of the act. On November 30, 1937, the first orders were issued establishing minimum prices and marketing rules and regulations. The orders became effective in the principal districts on December 10, 1937, and soon thereafter in the other districts. They were effective until February 25, 1938, when they were withdrawn after several Circuit Courts of Appeals issued restraining orders on the basis that adequate hearings had not preceded establishment of prices. The Commission then prepared a more comprehensive procedural program. Itemized cost data were gathered for the base year 1936, and these were adjusted for subsequent changes. Concerns reported for 1936 and monthly thereafter throughout 1937. Actual costs were also tabulated for the nine-month period April–December 1937—after new wage scales became effective. It was found that the average costs for the period April–December 1937 were about 11 cents per ton above sales realization. This difference is an indication of the average increase in price contemplated under the act for that period. Such increases appear to be extremely small, but they are sufficient to eliminate a menacing deficit on the huge tonnage of production.

Preliminary hearings on costs were held at Denver, Colo., for the far western districts, June 10–16, 1938, and for the other districts at Washington, D. C., July 6–23. The full Commission was present at all the hearings.

On March 30, 1938, the Commission announced its decision to open the individual cost returns of producers for inspection by parties who could show proper interest, but it was enjoined from doing so by a restraining order issued on behalf of the Utah Fuel Company and other producers. The United States Supreme Court, on February 5, 1939, sustained the Commission in its action to disclose the cost data.[21] Immediately the Commission opened the books to interested parties and announced reopening of hearings. In the meantime hearings had been held on the f. o. b. mine prices, and more than 9,000 pages of testimony were taken under General Docket No. 15, the cost-hearing docket.

Coordination of minimum prices involves knowledge of transportation costs. The Traffic Section of the Commission is compiling freight rates for coal moving from every origin rate group to all destinations served by rail in the United States. The files will contain more than 1,000,000 individual rates.

The Commission is also engaged in making a special statistical study of the distribution of coal for the year 1937. This study is undertaken for the purpose of providing basic data to be used in calculating the weighted average realization derived from the new price schedules, when issued. In addition, the results of the study will be of material value in the price coordination work.

The distribution study, when completed, will show the movement of coal from each rail-shipping mine to city of destination, by class and size of coal, by consumer use, by freight-origin groups, and by market area. This will be the most complete study of the movement of bituminous coal ever made, and will be of great value to all persons interested in the bituminous-coal industry.

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[20] *Second Annual Report of the National Bituminous Coal Commission*, Washington, 1939, p. 1.

[21] 83 Law Ed. 402 (1939).

Copies of contracts and spot orders have been required since June 1937, and copies of all invoices and credit memoranda since January 1, 1938. The number of spot orders runs to hundreds of thousands per year and the number of invoices to millions. It is interesting to note that the average invoice received covers only 94 tons of coal.

District boards were directed to complete by March 15, 1939, coordination of minimum prices and marketing rules and regulations in common consuming markets, but, again, as in the latter part of 1937, most of the district boards failed in the assignment. Thereupon the Commission proceeded in lieu of the boards with the coordination. Price classifications for coal produced by each code member will have to be completed, and complaints will have to be heard before the coordinated prices are applied.

Nine cooperative marketing agencies, whose members had an aggregate output of 129,000,000 tons in 1936, applied by November 15, 1938, for approval under section 12 of the act. It is contended that the agencies will aid in enforcement. The agencies are unlawful unless member producers have accepted the Code promulgated under the act.[22]

A gigantic task confronts the Commission. It probably will be some time before the machinery for control of minimum prices is again ready, but price control established after thorough study, such as has been undertaken, stands a better chance of ultimate success than action based on hasty improvisations. Much of the work of the Commission is without precedent, and, of course, pioneering is more difficult than operation on the basis of past experience. The real test will come when price regulation is reestablished on a going basis and the initial stages are considered to have been past.

Outlook and Probable Effects of Regulation

Even though Federal regulation of the bituminous-coal industry will encounter perplexing problems, the prospects are that the new Coal Act will be retained, perhaps with modifications, through the 4-year period fixed for its duration and that demands will be made for its renewal or supersession by another regulatory act. It appears that only an unmistakable reversal in the trend of recent Supreme Court decisions will lead to invalidation of the act. Miners undoubtedly will be favorable toward the act unless there is an unforeseen setback in wage rates and other conditions of employment. Although it is difficult to see why the majority of operators might oppose the regulation, it is likely that some will oppose it on the basis that it weakens their competitive position, establishes a level of prices sufficient to cover only average costs, reduces flexibility in the pricing of the various classes of coal, and encourages the use of substitute fuels. Opposition may also come from coal consumers and coal dealers, since preservation of interdistrict competitive relationships requires a system of freight absorption, i. e., "discrimination" among consumers. The fact that systems of freight absorption (i. e., basing-point systems) long have been under Federal attack in other industries may provoke legal resistance by consumers. The more serious threat, however, may come from the complex problems of administration. Questions of legality may require such meticulous care in procedure that the aim of flexibility cannot be attained. Moreover, contradictions within the act (e. g., the aim of covering costs on the one hand and the aim of preserving competitive relationships on the other hand) are certain to present distressingly acute administrative and legal problems.

Undoubtedly, the Commission is aware of these hazards, and it is important to bear in mind that the act accords comparatively broad discretionary powers to the Commission. The courage and intelligence of the Commission will determine in large measure how equitably and efficiently the act is made to operate, although internal inconsistencies may require statutory remedy. Growing complexity of problems will tend to be countered by growing experience and skill in administration. That a tolerable regulation is possible is indicated by the fact that substantially the same kind of act was on a working basis before being declared invalid in the *Carter Coal* case.

No doubt the efforts of the Commission will be absorbed mainly in administering the price-fixing features of the act. Under the National Recovery Administration the Code Authority had responsibility for about 30,000 minimum coal prices, and no reduction in that number was contemplated under the present act; in fact, multiplication of the number is certain.[23] Individual consideration cannot possibly be given to many thousands of prices. If only one minute were devoted to each price (some should be given hours of time), it would require 63 days of eight hours each to examine a list of 30,000 prices. Moreover, changes will be made among the prices for the various classes of coal; petitions and complaints in regard to the prices will be received.

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[22] Greater dependence on self-regulation by means of marketing agreements among producers and distributors is the chief feature of a bill (H. R. 5119) introduced on March 20, 1939, by Representative Robert Allen, of Pennsylvania, to amend the coal act. The bill provides for elimination of the price-fixing features, the 1-cent tonnage tax, the district boards, and the 30-day limitation on contracts. It would make information submitted by producers and distributors confidential unless consent for disclosure is obtained or the information is submitted in hearings before the Commission or a court. Membership of the Commission would be reduced from seven to three, and jurisdiction would extend to all coal except anthracite. The bill has been referred to the Committee on Ways and Means, but no further action has yet (April 12, 1939) been taken.

[23] *Hearings, op. cit.*, p. 78.

Under the act, average cost of production is the basis for determining the level of the minimum prices. In view of the attempt to guarantee coverage of costs, it might be thought that coal producers would have the incentive to count into expenditures every possible item. It must be remembered, however, that each producer and each district likewise has the incentive of securing a price low enough to permit the retention or extension of his or its markets.

Moreover, price increases for coal are recognized in the industry as a not unmixed blessing.[24] Higher prices for coal are a direct penalty to consumers of coal, and, unless great care is exercised, they are likely to have adverse effects on the coal industry. Greater economy in the use of coal and accelerated shifting to substitute fuels are almost certain consequences. Within the industry, new competition may spring up if and when it is realized that the coal industry may offer prospect of profits coupled with loss limitation. Thus, higher prices may stimulate additions to capacity in an industry already suffering from excess capacity.

Although the act does not provide for direct administration of labor relations, no doubt the act is favorable to the interests of the miners. Higher wage rates, however, will stimulate the introduction of labor-saving machines. Owing to some assurance against loss and to improved financial condition, operators will feel freer to make capital outlays for mechanization of the mines.

A shift of competition from a price to a quality basis is another possible effect of the regulation. If producers are no longer permitted to attract trade by offering price concessions, they may be expected to redouble their efforts to raise the standards of quality and service to a higher level (even to the extent of underclassification). There is also the prospect that coal producers, denied the right to use price cutting as a competitive weapon, may turn to the field of distribution to expand their markets. The price structure established by the Commission may tend to encourage the adoption by producers of this added function.

Finally, it may be observed that the extent of exemption from Federal regulation accorded to intrastate producers is not yet a settled question. A court battle relating to exemption of intrastate producers from the 19½-percent tax and other provisions of the Coal Act has been started. If liberal exemption is granted for coal sold in intrastate channels, Federal regulation of the industry will be greatly weakened if not rendered ineffective. The implication of the *Carter Coal* case decision is that the price-fixing features of the 1935 Coal Act are constitutional. The 1937 act was written so far as possible to stay within the limits of the Court decision, and, therefore, a presumption of legality seems reasonable.[25] Moreover, the Court was divided five to four on the majority opinion. A subsequent change of attitude on what constitutes (1) commerce and (2) interstate commerce should be noted. Labor provisions of the 1935 act were declared illegal on the ground that they applied to production rather than to commerce, and, therefore, that they did not fall within the interstate commerce power of Congress. Three history-making opinions delivered by the Supreme Court on April 12, 1937, have upset previous notions not only with regard to the dividing line between production and commerce but also to the extent of Federal jurisdiction over commerce.[26] In the *Jones and Laughlin Steel Corporation* case, it was indicated that even though activities be intrastate when separately considered, if they bear a "close and substantial" relationship to interstate commerce, so that control is needed to protect that commerce from "burdens and obstructions," Congress cannot be denied power to exercise control. Although all three concerns involved in the cases were producing (manufacturing) organizations, they were declared subject to Federal regulation under the interstate commerce clause.

An opinion involving the National Labor Relations Board and the Consolidated Edison Company of New York (the company serving 3,500,000 customers in New York City and Westchester County, New York), delivered December 5, 1938, further clarifies the position of the Court.[27] In this case it was decided that, despite the intrastate character of the power company business, the company supplied service to transportation and communication industries and to Government activities which "in their totality rise to such a degree of importance that the fact that they involved but a small part of the entire service rendered by the utilities in their extensive business is immaterial in the consideration of the existence of the Federal protective power." It is possible that the existence of public utility status may have led the Court to attach a higher degree of Federal interest to the company than it would have attached to a nonutility company, but this fact seems not to have been given any considerable weight.

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[24] See *Unemployment and Relief, Hearings on Senate Resolution 36*, 75th Congress, third sess., vol. 1, January 4 to 22, 1938, p. 519.

[25] On February 16, 1939, a three-judge statutory court in the U. S. Court of Appeals for the District of Columbia held the price fixing provisions legal. Cf. *Black Diamond*, February 25, 1939, p. 10.

[26] *National Labor Relations Board vs. Jones and Laughlin Steel Corporation*, 301 U. S. 37; *National Labor Relations Board vs. Fruehauf Trailer Company*, 301 U. S. 53–54; *National Labor Relations Board vs. Friedman-Harry Marks Clothing*, 301 U. S. 72–74.

[27] 83 Law. Ed. 131 (1938).

In 1929 about 74 percent of the total national supply of bituminous coal available for sale entered directly into interstate commerce or was delivered to carriers subject to regulation by the Interstate Commerce Commission.[28] Extension of Federal regulation to cover a major share of the intrastate commerce in addition to the interstate commerce would leave only a small percentage of the total beyond the reach of Federal jurisdiction.

Much of lasting value has been accomplished by the experiments in regulation already attempted. In the first place, a stable level of wages has been maintained since the drive for unionization of the miners during the early days of the N. R. A. Although falling short of its objective, the administration of the 1937 Coal Act has furnished considerable experience and should help to indicate the way to progressive action. Whatever form of regulation is attempted in the future, and it is generally conceded that some form of regulation is necessary, it will be well to make changes only after careful comparison of performance under the act with that in previous periods.

Despite all possible steps taken to restore order to the coal industry, there will remain the problem of competing fuels. The economics of the coal industry and of oil, gas, and water power call for a coordinated energy policy for the Nation—not detailed administration, but rather a policy that leads enterprise to make a better adjustment of energy utilization to availability of resources.

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[28] F. G. Tryon and W. H. Young, "Distribution of Bituminous Coal, Classified as Interstate, Intrastate and Railroad Fuel, 1929," *Supplement to Monthly Coal Distribution Report No. 58* (mimeographed), United States Bureau of Mines. The percentage quoted does not include "local sales," aggregating 4.37 percent of the total. A small but indeterminate part of these sales entered interstate commerce.

CHAPTER 2.—ECONOMIC AND SOCIAL CONTROL OF THE COAL MINING INDUSTRY IN EUROPE [1]

By Lewis L. Lorwin [2] and Arthur Wubnig [3]

The development of a system of economic and social control for the coal-mining industry in the United States has its parallel in other countries and may thus be regarded as part of a world-wide tendency. In most countries where coal mining is important, but especially in Europe, the coal-mining industry is rapidly evolving out of the economics of "free competition" into the economics of "control"; in all European countries where coal is mined on a large scale, its production, marketing, and pricing are largely governed by combines, cartels, and marketing schemes which have a public or semipublic status, and by special regulatory legislation. Furthermore, regulatory devices to govern the flow of world trade in coal and coke have also begun to evolve.

The Growth of Control Schemes in European Coal Mining

Certain tendencies toward the integration and combination of collieries, toward public and quasi-public regulation of coal mining had made headway in Europe long before the outbreak of the World War. Thus, the great regional cartels of Germany (above all, the Rhenish-Westphalian Coal Syndicate) came into being in the last decade of the 19th century; that same decade also saw the founding of the Central Committee of Collieries in France and the first significant steps toward amalgamation of collieries in Great Britain. These early tendencies were considerably forwarded during the years of the World War. Each belligerent power was under the double necessity of exploiting to the full all its mining facilities and of applying the largest possible supplies of coal to the greatly enlarged demands of munitions and armaments factories, metallurgical and chemical plants, the railroads, and the merchant marine. In almost every belligerent country the coal-mining industry was placed under strict governmental control, direct or indirect, to stimulate production and to ration consumption.

Although the rigid war-time controls were relaxed with the return of peace, the post-war period up to 1929 brought into play forces which gave added strength to the evolution of regulatory devices. Throughout Europe the productive capacity of coal mining rose to ever-higher levels; new mining facilities were developed in Germany (lignite), in Belgium (the Campine Field), in the neutral countries (e. g., Spain and the Netherlands,; a great shift from hand mining to mechanical mining took place—above all in Germany (the Ruhr); reconstruction of devastated mines enlarged the pre-war capacities of France and Belgium. At the same time the growth of demand for coal in Europe and elsewhere was held down by two technological factors above all: (1) by the progress of fuel efficiency in metallurgical and thermo-electric works, in steam-raising plants as well as on railways and steamships; and (2) by the substitution for coal of fuel oil (the merchant marine) and of water power (Switzerland, Sweden, Italy). Simultaneously, the pre-war channels of the world coal trade, and especially of the coal trade in Europe, were radically transformed under the impact of deliveries of coal as reparations in kind and of the shift of mining facilities from old to new political sovereignities; the volume of trade was made to suffer at the same time by the growing pressure of economic nationalism.

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[1] This section is summarized from the *Report of the International Labor Office to the Technical Tripartite Meeting on the Coal Mining Industry*, Geneva, May 1938. See pt. I, ch. 9. Because of the date at which that report was prepared, it could take no account of the important territorial modifications in Central Europe during the autumn of 1938 and the spring of 1939.

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[3] Member of Economic Section of the International Labor Office.

In the course of this three-fold evolution, coal mining in Europe was brought face to face with a problem of "surplus capacity" which was as acute as it was far reaching. National and international experiments for the control of the industry were the response. In Great Britain, during 1927 and 1928, at least three mining districts—South Wales, five Midland Counties, and Scotland—were led to experiment with local schemes for the control of output and capacity, of marketing and pricing. In Germany, the pre-existing regional cartels came to acquire a compulsory legal status as the sequel to the legislation of 1919 (which had the eventual collectivization of coal mining as its nominal end in view). In Poland the Polish Coal Convention was set up in 1925 as a national integration of three district cartels. In 1927 an international understanding to maintain reasonable price levels in their sales to certain French markets was reached by the colliery owners of the North of France, the Ruhr Basin in Germany, Belgium, and the Netherlands.

Far-reaching experiments in the contrivance of regulatory devices were greatly stimulated after 1929 by the economic difficulties of the Great Depression and by the movement toward national self-sufficiency; this stimulus still continues in force. The coal mining industry of Great Britain has been made to function under a national system of control by virtue of the Coal Mines Act of 1930 as subsequently amended; the regional coal cartels of Germany have been "coordinated" (since 1933) within the framework of a "totalitarian" economy; the Polish Coal Convention has been expanded to cover the overseas export trade and turned to fuller use as an instrument of national economic policies (1932 and subsequently); a system of zoning home markets and of maintaining minimum prices has been worked out among the mining districts of France (since 1931); national control schemes have been set up for the collieries and cokeries of Belgium (since 1935). An international agreement to regulate export volumes has been reached between the colliery owners of Great Britain and Poland (1934, renewed in 1937); while an international coke cartel has been set up by the exporting interests of Germany, Great Britain, the Netherlands, Belgium, and Poland (since 1937).[4] The international trade in coal and coke, especially as between European countries, has come under the rule of bilateral accords, barter agreements, preferential trade treaties, quota limitations of imports, payment restrictions in foreign exchange, and clearing agreements. There has emerged, in sum, an intricate network of regulations, intranational and international, which covers the whole of Europe's coal-mining industry.

Integration as a Factor in European Control Schemes

Underlying this highly developed system of national and international economic control is a condition of advanced financial integration, horizontal as well as vertical. Both forms of integration are found side by side in all European countries; in many, if not in most cases, the same community of ownership which extends over a number of coal or lignite workings (horizontal integration) also extends over a financial complex of collieries and other industrial works (vertical integration).

Except for bituminous coal in Great Britain and lignite deposits in Czechoslovakia, horizontal integration of mining facilities is far advanced in all European countries. In the Soviet Union, under a "collectivist" regime, the whole of the coal-mining industry is operated as one giant State enterprise. In Germany the entire output of the Ruhr Basin is obtained by 33 undertakings and that of the Aachen district by four enterprises; the coal mines of the Saar are all State-owned; a handful of producing interests account for almost all of the output of West Silesia; lignite capacity is likewise concentrated in a few hands. The total productive facilities of France are under the ownership of about 100 undertakings; 11 enterprises out of 26 are responsible for more than nine-tenths of the regional production in Nord and Pas-de-Calais, while the whole tonnage of Lorraine is obtained by two huge undertakings. In Poland the complete capacity of East Upper Silesia is worked by less than 20 colliery enterprises, which are so merged together for marketing purposes that almost the whole of this basin's output is marketed through 6 sales concerns. In the Netherlands two-thirds of the national output is controlled by 4 State-owned mines, while the remainder comes from 4 private collieries. In Belgium, where the colliery operations number 80-odd, almost half of the output is controlled by a few investment banks, which own large blocks of shares in colliery undertakings. In Great Britain the entire anthracite capacity of South Wales is worked by what may be regarded for all practical purposes as a single community of financial interest. And although ownership of bituminous facilities is widely diffused in Great Britain, about three-fourths of the productive capacity is concentrated in about one-half of the pits and in about one-fourth of the producing interests. Despite the absence of integration in the lignite workings of Czechoslovakia, about nine-tenths of the output of bituminous coal is obtained by 10 enterprises.[5]

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[4] Early in 1939, there were unofficial reports in the European press that an agreement on export tonnages and on export markets had been reached between the coal mine owners of Great Britain and Germany, and that this agreement would presently be generalized to include all European countries exporting raw coal. Soon after these reports were published, considerable political tension developed in Europe, so that useful details of the agreements are not available at this time.

In all European countries the vertical integration of collieries with other industrial plants is superimposed on the horizontal integration of collieries by themselves. In Germany, well over two-thirds of the output of the Ruhr is obtained from collieries which are joined in common ownership, private or State, with iron and steel works, other metallurgical works, thermo-electric stations, chemical and gas supply plants, railroads, arsenals, and shipyards, etc. All the output of Aachen and virtually all that of West Upper Silesia are likewise obtained from "factory" mines which are bound in ties of common ownership to metallurgical works; the State-owned collieries of the Saar supply much of their output to industrial plants, public utilities, and transport enterprises that are also State-owned; much of the lignite capacity is "captive" to the needs of thermo-electric and chemical plants or of sugar refineries, paper mills, cellulose plants, glass and porcelain works. Although commercial collieries, which mine exclusively for open-market sales, raise the great bulk of bituminous output of Great Britain, many of the larger bituminous properties are owned by or form a financial entity with iron and steel works. In South Wales, moreover, the anthracite collieries are interlocked financially with chemical undertakings in particular. In France, not more than one-tenth of the national output of coal (mainly in Lorraine) is obtained by "captive" mines which supply the fuel requirements of metallurgical or chemical works or railway systems. On the other hand, the great bulk of the national capacity belongs to collieries which are tied in, through interlocking communities of financial interest, with metallurgical and chemical works, with thermo-electric plants, and with gas supply stations. In Belgium, the existence of true "captive" mines (attached to iron and steel works) is supplemented by the common control which a few investment banks exercise over much of the metallurgical and mining capacity. Integration of privately owned collieries with metallurgical works and of State-owned collieries with State-owned railways is highly developed in the East Upper Silesia district of Poland. Autonomous undertakings are the general rule in Czechoslovakia,[6] but a substantial part of the national output comes from "captive" and from State-owned mines. In the Netherlands, much of the output of the State mines goes to satisfy the fuel and power requirements of other public undertakings.

The National Schemes of Control in Europe

The national control schemes of Europe are aimed as much toward meeting the marketing problems of world trade as toward coping with the internal problems of the several national economies. This duality of purpose arises, first, from the high ratios of export shipments to total output in such countries as Great Britain, Germany, Poland, the Netherlands, and Belgium; and second, from the considerable volume of import shipments into several of the coal-mining countries such as France, Germany, Netherlands, and Belgium. The control schemes are described below as they existed of recent date (1936–1938) in the main coal producing countries of Europe.

The Soviet Union.—The control of coal mining in the Soviet Union is a unique case. Subject to the directives of national planning on the basis of the collective ownership of all the means of production, the fundamental principle is that of State-owned properties to be managed by State trusts. Thus, in coal mining more than nine-tenths of the productive capacity is worked by 42 regional trusts which are grouped under the Glavugol, an organ of the Commissariat for Heavy Industry.

Germany.—The profound changes which the economic order of Germany has undergone since 1933 and which it is still undergoing today are more or less common knowledge, so that it is unnecessary to attempt here even a cursory sketch of the evolving structure of State control. So far as coal mining is concerned, two broad tendencies may be noted: first, the emergence of an elaborate pyramid of regulation with its base in regional cartels, its intermediate structure in such bodies as the National Coal Federation and the Economic Group of the Mining Industry and its apex in the Minister of National Economy; second, the ever-closer articulation of coal mining into a "totalitarian" structure which covers the whole of the national economic life.

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[5] The situation in Czechoslovakia as here described refers to the period before the territorial changes of September 1938 and before the larger territorial changes of March 1939. The result of these changes was that practically all of the coal mining capacity of Czechoslovakia was transferred to Poland or came under effective control by Germany.

[6] See footnote above.

For practical purposes it will suffice to consider the set-up and activities of the regional cartels into which the entire productive coal capacity of coal mining is organized. Under the new form of the State since 1933 as under the old form of the post-war years, it is these regional cartels which underlie and give effect to the economic control of coal mining in Germany; their significance for control arises out of the powers which they wield over output and sales, over marketing and prices. Every colliery is under the legal compulsion of adhering to the regional cartel of its own district; so that the cartels might be described as quasi-public bodies which make up, in their totality, a system of quasi-public control.

There are 10 such regional cartels;[7] of these, the Rhenish-Westphalian Coal Syndicate is by far the weightiest, for its member collieries produce over four-fifths of the national output of bituminous and anthracite and supply almost the whole of Germany's exports of raw coal. Other major regional syndicates are: for coal, those of West Upper Silesia and of West Lower Silesia; and for lignite, those of the Lower Rhineland, Central Germany, and East of the Elbe. It might be well to consider the Rhenish-Westphalian Coal Syndicate as a representative case.

This is a highly developed cartel to which all collieries of the Ruhr and Aachen districts are required to belong and to which the State-owned mines of the Saar also adhere. First, the Syndicate allots output quotas and sales shares to each of its member collieries. The output quotas fix the total tonnages which any mine may raise and the sales shares fix the total tonnages which any mine may sell. Second, the Syndicate acts as the exclusive agent through which every member colliery must market the whole of its sales share (as distinct from the tonnages mined for colliery fuel, for self-consumption by industrial works under common ownership, for cheap sale or free delivery to mine workers, etc.). This means that the Syndicate is an instrument for centralized marketing of output in home and foreign markets. Third, the Syndicate fixes the minimum pithead prices, of official force, which shall prevail for quantity sales to any and to all of the "noncontested" home markets where it enjoys a complete or practical monopoly. Its "noncontested" markets include the whole of Germany save for the cities of Hamburg and Bremen and the regions East of the Elbe. Fourth, the Syndicate reserves to itself the right of selling direct to a number of large consumers (e. g., the state railways, municipal gas works and thermo-electrical plants, big metallurgical establishments, etc.) and disposes of the remainder of its supplies through wholesale agencies, each of which is granted exclusive marketing rights over a given region. Fifth, the Syndicate levies an equalizing or compensatory tax (Umlage) to make up for the losses which it may have to sustain on the marketing of coal to "contested" markets—mainly abroad but also in Germany—at prices which are determined by the exigencies of local competition. The Umlage is charged back to the individual collieries on a tonnage basis at levels which are somewhat higher for the sales share alone than for the rest of the output quota: exempted from the Umlage, moreover, is almost a third of such tonnage as is consumed by affiliated industrial works.

In sum, the Syndicate is a carefully wrought device for enforcing what may be regarded as a monopoly control over the great bulk of Germany's home market and for promoting a maximum of export shipments. The Umlage has to be regarded as the financing implement of an export bonus, for it recaptures part of the monopoly profits from sales to "noncontested" markets in Germany to pay for the losses from sales to competitive markets abroad and at home. With variations, the practices of the other regional cartels tend to approximate those of the great Syndicate of the Ruhr, so that each mining district tends to be vested with monopoly powers over certain home market zones from which the other districts are effectively excluded by the burden of transportation differentials in the main. As for the home market in its entirety, it is protected against a possible flood of imports—particularly at Baltic ports—by virtue of import quotas, licensing of payments in foreign exchange, and minimum price safeguards. If some measure of interdistrict competiton for the home market still persists, it does so only in those few neutral areas where, as transportation differentials wear thin, the frontiers between "contested" and "noncontested" markets tend to blur.

Great Britain.—The national control plan is based on part I of the Coal Mines Act of 1930 as subsequently amended. First, the country is divided into 17 mining districts, each under the regulation of an Executive Board of the colliery owners. Second, national coordination is assured by a Central Council of the colliery owners. Third, the objectives of control include limitation of output, market sharing, price maintenance, and centralized selling.

The main task of the Central Council is to allot regional output quotas to each of the 17 mining districts. Separate quotas are established for tonnages to be sold to the inland trade and for those to be sold to the export trade. The Central Council is thus engaged in the sharing out of markets between districts and does so by limiting the volume of output for each. Its major difficulty has been the allotment of the inland quotas; for the depressed mining districts of the shrinking export trade (e. g., South Wales) have sought to obtain larger inland quotas against the resistance of other mining districts (e. g., Lancashire, the Midlands) which supply mostly to British consumers.

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[7] It was impossible to learn at this time what disposition under the regional cartels would be made of the Czechoslovakian lignite mining districts over which Germany assumed effective control in March 1939.

In each of the 17 districts the Executive Board has a two-fold task. First, it has to distribute the inland and exports quotas among the individual collieries, and, second, it has to draw up schedules of minimum pithead prices. The orders of the Executive Boards on quotas and prices are subject to appeal by mining and consumer interests which may be aggrieved; investigating committees hear such appeals and report back to the Board of Trade, which is competent to issue the appropriate recommendations where necessary.

Since the summer of 1936, centralized selling schemes have been put into effect in almost all of the districts. These schemes fall into three main types: (1) complete centralized control of sales, where the whole output of the district is marketed through a single agency; (2) grouping of the collieries within a particular district into a number of central selling agencies; and (3) central supervision over and coordination of sales with each colliery free to conduct its own marketing.

In the curbing of competition between individual collieries of the same mining district, the British scheme of control would seem to be quite effective; but it does not as yet provide for a close and effective regulation of competition between mining districts. Despite the output quotas which are allotted to each district for inland and export sales, interdistrict coordination of pricing still remains to be achieved. Each Executive Board is free to set minimum prices much as it sees fit, while the fixing is of pithead rather than of delivered prices.

Part II of the Coal Mines Act of 1930 looks toward the compulsory amalgamation of individual collieries through the exercise of its powers by the Coal Mines Reorganization Commission, a quasi-judicial body. Because of the limited powers of this body as well as the procedural complications involved in their exercise, little progress has been made to date. More practical results may follow, however, out of certain procedural reforms of recent date and out of Parliamentary enactments which have the nationalization of coal royalties in view.

France.—The scheme of supervision in France includes the following main elements: (1) To regulate competition between mines in each district, the collieries of each basin are joined in regional marketing combines, of which the largest (*Comptoir de Douai* in the Nord and Pas-de-Calais) regulates the marketing of two-thirds of the national output. (2) To zone out the home market among the several mining districts, the three regional combines of the north, the east, and the center and south are parties to an agreement for dividing most of France into several regional spheres of preferential influence. (3) To supervise competition in the coastal areas which lie outside the zones of preferential influence, a Joint Sales Bureau has been set up by the colliery owners and the coal importers. (4) The coal mines of the north of France are parties to an international agreement with those of the Ruhr, Belgium, and the Netherlands to maintain reasonable price levels in certain French markets. (5) The equilibrium of the home market is maintained against import disturbances by a far-reaching system of quota limitations. (6) The Government is empowered to fix maximum prices for coal.

Because of the great volume of France's coal imports, the major problem of control is to keep a competitive balance between home output and import shipments. This problem would seem to be largely solved by the marketing arrangements which prevail plus the import quotas in force. Only minor frictions of interdistrict competition for the home market have to be met.

Poland.—The essential instrument of control is the Polish Coal Convention, a nation-wide cartel which covers all three of the mining basins.[8] Although individual collieries retain the freedom to make their own sales, production and marketing are regulated as follows:

(1) Total output quotas are assigned to each mine. (2) Each mine is assigned a threefold sales share which limits its deliveries: (a) to the Polish home market; (b) to foreign markets reached by inland routes; and (c) to foreign markets reached by overseas shipments on the Baltic. (3) Schedules of minimum pithead prices are drawn up for sales to each of these markets, subject to the Government's power to set maximum prices for the home market. (4) Provisions are made for the grading and classification of coals, and each mine is required to adhere to the grades and classifications as thus defined. (5) At various times, such as 1931–32, the Convention has served as a quasi-public instrument for implementing a variety of export subsidy measures.

The circumstance that Poland must export, year in and year out, about a third of its total coal production is of basic importance to an understanding of the Polish Coal Convention. It has aimed to regulate competition between mining districts and individual mines during a period when the "natural" export markets of Poland (inland Europe) were sharply contracting. It has also aimed to maintain home market prices at levels which would allow export coal to be shipped overseas, in competition with fuel from Germany and Great Britain, to Western Europe, Scandinavia, and the Mediterranean. Because of the price burdens which the national market has been called upon to bear under this system, the Government has had to intervene for the protection of consumers. It is also empowered to control output, stocks, and sales of coal; to forbid exports or imports of coal when in the public interest to take such measures: to regulate the marketing of coal within Poland; to compel mine owners to organize and to vest their organizations with a quasi-public status.

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[8] It is not yet clear how the coal mining properties of Teschen, transferred from Czechoslovakia to Poland in the autumn of 1938, will eventually be fitted into the framework of the Polish Coal Convention.

Other countries.—In Belgium the National Coal Office exercises control over the production and marketing of coal, the Belgian Coke Office over the production and marketing of coke. Both are cooperative bodies of colliery or cokery owners: each is competent to assign output quotas. allot sales shares, engage in central marketing, etc. In the Netherlands there is a close coordination of marketing policy between the four State mines and the four private collieries; the quota limitations on imports act to reenforce such coordination. In Czechoslovakia a National Cartel was superimposed on a number of regional cartels; the marketing policies of the National Cartel were implemented through an autonomous Sales Society.

Control of the International Coal Trade in Europe

Only limited free play is allowed in the coal trade between European countries to such competitive advantages or disadvantages as ease of mining, closeness to markets, skill of labor, level of mechanization, etc., for the strictly economic factors of international competition have been blocked from full expression, especially since 1929, by a growing body of governmental measures which aim at safeguarding home markets and at winning preferential status in foreign markets. Simultaneously with these developments, a number of international combines and agreements have begun to function.

Customs duties upon imports of coal often rise to protective levels in European practice; this would seem to be true in the recent past of such countries as Belgium, France, and Czechoslovakia. Quota limitations are still more effective as a protective device; they were being applied against coal imports in 1936 by such countries as Germany, Belgium, France, Poland, and the Netherlands. In such countries as Germany and Poland the effect of quota limitations is reinforced by requiring that import licenses be obtained before payments of foreign exchange can be made.

Direct or indirect export subsidies are a widespread device in the efforts of European countries to promote their coal exports. In the form of direct bonuses or premiums such subsidies have been paid in recent years in Germany, Belgium, and Poland. In the indirect form of preferential freight tariffs on the railways they have been paid by Germany, Great Britain, Poland, Belgium, the Netherlands, and Czechoslovakia. Export shipments of coal have been granted special relief from tax burdens by Great Britain, France, Poland, Belgium, and Czechoslovakia. Wherever the machinery of marketing control has been highly developed, it has opened the way to, if not actually brought about, price discrimination between sales to home markets and sales to foreign markets.

Preferential trade agreements abound everywhere in the coal trade of Europe. Some of these agreements (e. g., those of Great Britain and of Poland with the Scandinavian-Baltic countries) fix the minimum share of its total coal imports which the importing country is bound to take from the exporting country. Other agreements fix the total tonnages which shall move between the exporting and importing countries (e. g., the agreement between Germany and Great Britain, the former agreement between Germany and Czechoslovakia). Still other agreements go so far as to reserve the whole of an import market to a single export supplier (e. g., the coal-livestock agreement between Great Britain and Ireland). Still others provide for the barter of coal against another commodity or service (e. g., the coal-tourist agreement between Germany and Switzerland). Many of the agreements (e. g., those of Germany with the Danubian countries) are part of a complex reciprocity of barter. Where elaborate import quotas are in force by a major importing country (e. g., France), or where the importing of coal is reserved to a State monopoly (e. g., Italy), or where licenses to pay for imports must be obtained from the Central Bank (all of the Danubian countries), the possibilities of negotiating preferential accords are particularly strengthened.

In short, the coal trade of Europe tends to be governed very much more by the checks and balances of "multilateral monopoly," than by such economic factors of "free competition" as differences of labor costs, transportation charges, and exchange rates. The resulting frictions have given rise during the recent past to two very significant experiments in the international control of marketing.[9] First, there is the Anglo-Polish Coal Agreement of 1934 as renewed, with modifications, in 1937. Second, there is the International Coke Cartel, which was founded in the spring of 1937.

The Anglo-Polish Coal Agreement is an understanding between the colliery owners of the two countries.

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[9] To these two experiments there was added in the spring of 1939 the possibility of an agreement becoming effective between the coal exporting interests of Great Britain and Germany. See footnote 4.

With reference to a group of important European markets, it is agreed that Poland's coal exports shall be limited in quantity, although the tonnage of British exports to the same markets shall remain unlimited. In the original form of the agreement, Poland's exports had to be held down to a certain percentage of Great Britain's; under the new form, however, the limitations on Polish exports may be calculated from a base which takes account of the combined exports in 1937 of Great Britain, Germany, Poland, Belgium, and the Netherlands. It is generally believed that this international broadening of the base may well be a step toward an all-European cartel of coal exporters.

The members of the International Coke Cartel are the exporting interests of Germany, Great Britain, the Netherlands, Belgium, and Poland. Export quotas are assigned to each of the five national groups (in percent): Germany, 48.43; Great Britain, 20.88; Netherlands, 17.83; Belgium, 9.66; Poland, 3.20. Import markets are divided into four zones of preferential influence; machinery is set up for the fixing and maintenance of minimum export prices.

Summary and Conclusions

Almost all the national control plans in Europe provide for the setting of output quotas and sale shares. Almost all of them likewise provide for the fixing of minimum pithead prices, particularly in home market deliveries. Most of them look toward the preferential zoning of home and foreign markets in favor of the individual districts and individual mines. Many of them provide facilities, where needed, for raising home market prices to monopoly levels in order to offset the competitive prices of sales to foreign outlets; the techniques for attaining this end frequently include compensatory or equalizing taxes. In countries where coal is mined on a large scale in several basins, the machinery of control ordinarily seeks to coordinate the marketing activities of the regional cartels or combines. The efficacy of the control machinery is usually enhanced by horizontal and vertical integration and by the commercial, transport, and fiscal policies which the government puts into force. Where the mechanism of control is international, its purposes are to regulate export volumes, to allocate export markets, and to maintain export prices.

Taking the national control schemes in the context of their international counterparts, it is clear that the regulation of coal mining in Europe gives rise to vast problems of public policy. First, there is the problem of setting up the safeguards which may be needed to reconcile the grant of monopoly power to private interests with the requirements of the national interest; second, there is the problem of how best to tie in the growth of commercial control with the progressive improvement of the labor standards of coal miners in all countries; third, there is the problem of giving due weight, in the contrivance of control schemes, to their possible effects upon the further use of substitutes for coal and the further development of fuel economies in its use; fourth, there is the problem of how to operate the control schemes in a manner that will relieve foreign trade in coal from harmful restrictions rather than burden it further with unreasonable restraints.

PART FOUR—SECTION V

TOWARD A FEDERAL POWER POLICY

By Leland Olds*

Federal power policy has developed as an outgrowth of the Government's responsibility for assuring use of the Nation's water-power resources in the public interest. As electric power became an increasingly vital factor in the well-being of the Nation, this responsibility necessarily broadened, but the essential concepts underlying the more recent developments were set forth in the reports of commissions appointed by President Theodore Roosevelt at the start of the conservation movement in the first decade of the twentieth century. Among these concepts was that of Federal control over the multi-purpose use of river systems.

Prior to 1920 the business of power supply in this country was essentially local in character. It had not yet reached the stage at which it could offer the Nation the most flexibly distributed and readily controlled form of cheap energy. Industry had not become dependent on central-station electricity, nor had power in the home and on the farm become an essential element in the standard of living. The development of hydroelectric power was largely associated with certain industries located at or near the power sites.

As explained in the first annual report of the Federal Power Commission, the laws governing the administration and disposition of water powers, prior to the Federal Water Power Act of 1920, were passed "at a time when there was little appreciation of the role which electric power would play in transportation and in industry, or of the safeguards which, in the disposition of this national resource, would be required in the interests of the investor as well as of the public."

As a result, although national leaders warned of the danger of permitting alienation of the Nation's major water-power resources to private interests, earlier legislation dealt chiefly with (*a*) the licensing of water-power projects involving the use of public lands and reservations of the United States, and (*b*) the conditions governing special grants for projects in the country's navigable rivers.

For projects in the first category, the act of 1901 superseded previous legislation and, until the enactment of the Federal Water Power Act, was practically the sole authority for water-power developments involving use of public lands. It limited the rights obtainable to mere revocable licenses, subject to the regulations of the executive departments. The Federal Power Commission estimated that, down to 1920, projects aggregating approximately 800,000 horsepower had been constructed under this act.

For projects in the second category, involving water-power developments in navigable streams, a special act of Congress was required in each instance. The general acts of 1899, 1906, and 1910 required the approval of the Chief of Engineers and the Secretary of War for project plans and fixed the general conditions under which the special grants were made. The 1910 act limited grants to 50 years, reserved the right to revoke the grant at any time upon payment of the reasonable value of the works constructed, and directed that consideration be given to the bearing of any proposed plan on a comprehensive scheme of development. The Federal Power Commission states that projects in this category, aggregating 481,550 horsepower, were constructed under special acts of Congress.

The Federal Water Power Act

The Federal Water Power Act of 1920, which created the Federal Power Commission with jurisdiction over the licensing of water-power developments in navigable streams and on the public lands and reservations of the United States, represented the first important broadening of Federal power policy. The approval of plans by the Chief of Engineers and the Secretary of War was continued under this act as a condition for the issuance of licenses affecting the navigable capacity of streams. Applicants were further required to furnish satisfactory evidence of compliance with the laws of the State or States within which their proposed projects were located.

The act limited licenses for such water-power developments to 50 years and provided for the right of the United States to take over projects at the end of the period or for relicensing in case this right was not exercised. It also provided for Commission supervision over the accounting of the licensee and for regulation of services and rates to the extent that State regulation was lacking. It prohibited the inflation of project costs through valuations placed on good will, going value, prospective revenues, or on water rights and lands in excess of the actual reasonable cost of such properties to the licensee at the time of acquisition.

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The Federal Power Commission was authorized to make investigations and collect data concerning the water resources of any region, concerning the water-power industry in relation to other industries, and concerning the relation of power sites to markets. It was further to consider whether power from Government dams could be advantageously used by the United States for its public purposes.

In issuing preliminary permits or licenses for water-power developments the Commission was required by the act to give preference to applications of States and municipalities. Furthermore, whenever, in the judgment of the Commission, the development of any project should be undertaken by the United States itself, the Commission "shall not approve any application for such project * * * but shall cause to be made such examination, surveys, reports, plans, and estimates of the cost of the project as it may deem necessary, and shall submit its findings to Congress," with recommendations for construction of the project.

Finally, the act expressly reserved the right of the United States, or any State or municipality, to take over and operate any licensed project at any time by condemnation and upon payment of just compensation.

Thus, the Federal Water Power Act laid the foundation for, and represented a long step toward, the establishment of the more fully developed Federal power policy which became necessary as a result of the tremendous changes in the power industry following 1920. It recognized the development of hydroelectric power as essentially a public business, which might be entrusted to private agencies only to the extent that private operation served the predominant public interest.

Regional Power Supersedes Local Power

The period 1920 to 1930 was not one in which public interest in the broader power planning provisions of the Federal Water Power Act found articulate political expression. As a result, the Federal Power Commission concerned itself almost entirely with applications of private interests for licenses to develop the Nation's hydroelectric power resources. Meanwhile the power industry was in process of rapid transformation from local to regional organization.

This transition was described by Joel D. Justin at the October 14, 1936, symposium on power costs, conducted by the American Society of Civil Engineers. Mr. Justin pointed out that during this period the development of long distance transmission to make low-cost hydroelectric power available at important industrial centers and the inefficiency of community power companies as a means of handling extensive distribution over wide territories led to the integration or coordination of such local companies into regional power systems. The tying together of regional power companies by means of high tension transmission lines followed. Territories covered by such systems sometimes exceeded 20,000 square miles and included populations numbered in the millions.

The transition was presided over by holding companies representing even more extensive financial interconnections. For example, the directors of the United Corporation could claim to speak for systems controlling more than 25 percent of the country's power supply and serving areas with a population of approximately 20,000,000. Connecticut, New York, New Jersey, Pennsylvania, Delaware, Tennessee, Georgia, Alabama, Mississippi, and Michigan were embraced by this combination, with contacts extending into Ohio, Maryland, and South Carolina.

The Federal Government Surveys This Result

The broadening of Federal power policy, to protect the public interest in the face of this transformation of the power industry, was preceded by the comprehensive investigation of utility corporations by the Federal Trade Commission, ordered by Senate resolution in 1928. This investigation developed, among other things, the extent to which the industry had become regional rather than local.

Transmission lines were found interconnected to form extensive networks. Energy transmitted across State lines reached significant proportions, totaling 13,799,000,000 kilowatt-hours in 1930, or 15 percent of all the energy generated by private companies in the United States.

The Commission found 16 large holding company groups controlling over three-fourths of the privately owned industry. It found, moreover, that the conduct of the power industry by these holding companies had been entirely out of line with the proper objectives of this major public business. It held that the evils and abuses fell chiefly into two classes:

> 1. Unsound and/or needless financial structures and practices which were a detriment and frequently a menace to the investor or the consumer or both.
>
> 2. The milking of operating companies through the devices of numerous forms of contracts and arrangements. * * *

The Commission characterized the ethical aspects of the situation by such words as "fraud, deceit, misrepresentation, dishonesty, breach of trust and oppression," and said: "The evils recited have flourished in spite of regulation as it has existed."

The Federal Trade Commission report was not completed until 1935, but the general findings had been constantly unrolled before the public eye as the investigation proceeded, and it had become increasingly clear that a broadening of Federal power policy was essential to protect the public interest.

Power Policy and Public Works

The foundations for such a broadening of Federal power policy were already being laid. The public works program, initiated in 1935, as part of the general attack on the depression and its causes, called for planning on a national scale, particularly in the field of conservation. The National Planning Board of the Public Works Administration in June of that year recommended a permanent national planning agency. Important steps providing the basis for an extension of Federal power policy followed:

1. The President, by Executive order of August 19, 1933, designated the Federal Power Commission to aid the Administrator of Public Works in the preparation of that part of the program pertaining to the development of water power and the transmission of electrical energy, and directed it to make "a survey of the water resources of the United States as they relate to the conservation, development, control, and utilization of water power; of the relation of water power to other industries and to interstate and foreign commerce; and of the transmission of electric energy in the United States and its distribution to consumers." This initiated the National Power Survey which established, for the first time, a firm foundation for the intelligent planning of future developments in the power industry, whether by Federal, State, or private agencies.

2. The Administrator of Public Works, in September, 1933, appointed the Mississippi Valley Committee to undertake a pioneer study of the possibilities of a unified plan for the development of an entire river basin, including flood control, power, navigation, reforestation, and prevention of soil erosion. The report of this committee dealt extensively with power as a coordinating factor in river development and suggested the possibility of a unified power supply system with Government control of the transmission function.

3. In April 1934 by resolution, Congress directed the Federal Power Commission to investigate, compile, and analyze the rates charged for electric energy by both private and municipal corporations throughout the United States. The resulting Electric Rate Survey revealed the wide variations between rates charged in different localities for the same classes of service. It effectively raised the question whether such variations were not the result of arbitrary and unjustifiable policies affecting the costs considered by regulatory bodies.

4. The President, by Executive order of June 30, 1934, established the National Resources Board (Committee) "to prepare and present to the President a program and plan of procedure dealing with the physical, social, governmental, and economic aspects of public policies for the development and use of land, water, and other natural resources and such related subjects as may from time to time be referred to the Board by the President." The reports of this Board, including that of the Mississippi Valley Committee which became its Water Resources Committee, have provided the country with its first comprehensive and detailed conservation program, including the orderly planning of public works to effectuate such a program.

5. The President on July 9, 1934, established the National Power Policy Committee of the Public Works Administration, composed of representatives of the several governmental agencies concerned with the Federal power program, "to develop a plan for the closer cooperation of the several factors in our electrical supply—both public and private—whereby national policy in power matters may be unified and electricity be made more broadly available at cheaper rates to industry, to domestic and, particularly, to agricultural consumers." The Committee was also directed to consider the lines which should be followed in drafting legislation "on the subject of holding companies and for the regulation of electric current in interstate commerce."

In connection with the development of Federal power policy, especially in relation to the growing recognition of Federal responsibility for proper conduct of the business of wholesale power supply, certain of the resulting reports require more detailed attention.

Full Use of Water Power Resources Through Interconnection

The October 1934 report of the Mississippi Valley Committee viewed power as "a coordinating factor in river development." It said: "Power, flood control, low-water control, navigation, irrigation, a widespread development of rural electrification, and an extensive national reserve against unemployment, appear inextricably bound up in the possibilities of the undeveloped waters of the Mississippi Valley." It saw "the unification of the national electricity supply" as a most promising key to the best use of the Valley's resources on a multiple-purpose basis.

The report called attention to "the low operating cost of hydro projects and the social advantage of utilizing an inexhaustible resource" as having a bearing on the decision to go forward with such developments. It suggested that the development of many power sites, which are relatively remote from consumption centers and therefore uneconomical to develop, will become feasible if such sites are tied into a region-wide system and particularly when such "regional transmission networks are interconnected over wide areas."

The report asserted that there was nothing novel in the conception of a completely unified system for generation and transmission of electricity and that the legal and operating problems should "appear relatively trivial in contrast to the great social purposes to be accomplished." To show the need for such "coordination and unification" it called attention to the "crazy patchwork" of operating areas, represented by the fields of operation of the leading private electric power groups, and the "mass of independent, unrelated, and frequently uneconomic generating units" involved in the municipal operations.

The report emphasized the extent to which such interconnection would release capacity at present necessarily held in reserve. It predicted, however, that measured against the greatly increased demand which the policy outlined would make possible, the output of existing systems, augmented by hydroelectric power generated by the Government as a part of its flood-control navigation power policy, would be found inadequate to meet long-range requirements. It continued: "The supply must still be supplemented by fuel stations, and happily the Mississippi Basin is rich in coal, lignite, gas, and oil."

The Committee suggested that this plan of power supply could "achieve its purpose only through the progressive building of group and regional and interregional transmission networks." It said that leadership was a task of government and continued:

> Just as the original impetus to interconnection was given by the Government during the World War, in requiring any company having excess capacity to transmit its surplus current to nearby territory in need of it, now the Government must take the lead if we are to achieve the unification desired in the new war upon economic waste and instability, unemployment, and the progressive destruction of basic natural resources.

The Mississippi Valley Committee thus emphasized the social and economic soundness of developing the country's waterpower resources in connection with general river development programs, if the power projects were hooked up by region-wide transmission systems. It envisaged ultimate interconnection of these regional systems, indicating that existing public and private systems would profit by cooperating in such a unified scheme.

Federal Concern for Ample Power Supply at Lower Cost

The first report of the National Resources Board (Committee) followed on December 1, 1934, dealing broadly with "National Planning and Public Works in Relation to Natural Resources." Its foreword began with the following statement of principle which underlies Federal power policy as an element in the general conservation program:

> The natural resources of America are the heritage of the whole Nation and should be conserved and utilized for the benefit of all of our people. Our national democracy is built upon the principle that the gains of our civilization are essentially mass gains and should be administered for the benefit of the many rather than the few; our priceless resources of soil, water, minerals are for the service of the American people, for the promotion of the welfare and well-being of all citizens. The present study is carried through in this spirit and with a desire to make this principle a living fact in America.

In its section dealing with hydroelectric power the National Resources Board formulated the broad outlines of Federal power policy on the basis of this principle. It first called attention to the extent to which "the historical development of technology is the story of man's achievements in converting, controlling, and utilizing the energies latent in natural resources" and, on this basis, asserted that "one of the objectives which national planning should strive to attain is to provide all sections of the country with all the electric power they may require at the lowest possible cost." The report continued:

> From the long-run viewpoint, the desirability of conserving natural resources makes the full utilization of all available water power seem highly desirable. Every unit of coal, gas, or oil burned is so much deducted from irreplaceable supplies. Water power, on the other hand, is a self-replenishing resource. * * * Indeed, the power of a running stream is lost every minute that it remains unharnessed, whereas a ton of coal not raised today is available for use tomorrow or the day after. Nor does the use of water to generate electricity harm it for drinking, or bathing, or transporting goods—coal, oil, and gas are destroyed by burning.

The report called attention to the fact that "as matters now stand, commercial enterprises seem unlikely to push the development of water power much further in the near future." It explained this on the ground that, from a strictly commercial viewpoint, most of the remaining water-power sites were, for one reason or another, undesirable, but held that the Government "can take a broader and larger view of the returns than commercial companies can afford to take."

The report then called attention to the fact that a vast potential demand for electricity in the household, the farm, the community, and the shop has not yet been tapped. It continued: "What keeps this potential demand from becoming effective are the relatively high charges for electricity that prevail in many sections. Recent studies of domestic consumption in low-cost municipalities, demonstrate that the demand for current is highly elastic, expanding rapidly as the cost declines." It cited the following comparative figures for average residential consumption and rates in 1933:

	Consumption	Rates per kilowatt-hour
	Kilowatt-hour	
United States	604	$0.0549
Seattle	1,089	.0258
Tacoma	1,550	.0173
25 Ontario cities	1,780	.0145

After suggesting that the transmission function, tying together generation and distribution to consumers, seemed to afford the best opening for systematic planning of economical power supply, the report concluded:

> The Government has an interest in extending the use of electricity as an increasingly significant item in the American standard of living. Hence it has an interest in the reduction of rates to stimulate consumption. It has a special interest in the development of hydroelectric plants as a means of conserving the country's resources in coal, gas, and oil. In some cases its plans for flood control or other uses of water would enable it to provide hydroelectric power as a byproduct at slight direct cost. The Government will not fail to consider as factor in the total situation the large sums of capital actually invested by power companies. The critical questions for the Government are how far the elasticity of the demand for electricity and the economies produced by interconnecting transmission lines may make it possible to reconcile these seemingly conflicting interests, and, to the extent that reconciliation is not possible, which interests should be given preference.

This report represented an important contribution to the formulation of Federal power policy. It recognized that within the limits of our resources all sections of the country should be assured all the electric power they could use, at the lowest rates economically possible. It pointed out that use of the Nation's inexhaustible water power resources would have the effect of preserving other irreplaceable energy and that Government, in dealing with the matter, could take a broader view than commercial companies of the economics of hydroelectric undertakings.

Federal interest in expanding the use of electricity, as an increasingly important factor in the American standard of living, the report showed, resulted naturally in concern for such reduction in rates as might be necessary to accomplish this objective.

Continuing Survey of Nation's Power Resources and Requirements

The preliminary National Power Survey report of the Federal Power Commission described the survey as the first attempt "to determine from a national standpoint the relation between present and future requirements for electrical energy and the capacity to meet such demand." It added that there had been no previous "appraisal of the efficiency of the generating plants of the major public and private utility systems."

The report pointed out that such a survey provides a sound basis for a public works program and is an essential factor of national defense. Noting that 2 years are required to plan and construct a large modern steam plant and from 2 to 7 years to plan and build a large water power project, it stressed the wisdom of planning in advance to meet increased demands for power. It asserted that the national interest required the most accurate possible inventory of the Nation's undeveloped water power resources in their relation to the present and future markets for power. The report stated:

> Careful planning under Federal supervision of new power plants and facilities for transmission is required to promote the safety and welfare of the Nation. Selection of sites for hydro or steam plants, to be developed either by public or private agencies, should take into consideration not only the pertinent engineering and economic factors but also considerations of broad national policy.
>
> Control of power is a social as well as an engineering and economic problem * * *. Modern civilization would collapse with the failure of the sources of electric light and power.

The National Power Survey report thus emphasized Federal interest in the Nation's power supply, with especial reference to planning for immediate requirements and for expansion to meet the demands of the future. It recognized that the safety and welfare of the Nation required a continuing inventory of power facilities, resources and requirements, including a constant appraisal of the relative efficiency of existing plants.

Importance of Economical Integration of Private Facilities

The report of the National Power Policy Committee, with respect to the treatment of holding companies, was transmitted by the President to Congress on March 12, 1935. Its broad recommendations called for the elimination of holding companies where they served no demonstrably useful purpose in the business of power supply and for simplification of existing systems by "the elimination of unnecessary corporate complexities and of properties which do not fit into an economically and geographically integrated whole."

The report pointed out that "while the distribution of gas and electricity in any given community is tolerated as a natural monopoly to avoid duplication of plants, there is no justification for an extension of that idea of local monopoly to embrace the common control, by a few powerful interests, of utility plants scattered over many States and totally unconnected in operation. Such intensification of economic power beyond the point of proved economies not only is susceptible of grave abuse but is a form of private socialism inimical to the functioning of democratic institutions and the welfare of a free people."

The report further noted that the growth of holding company systems had "often been attained with the great waste and disregard of public benefit," that the controlling groups had "in many instances paid no more than lip service to the principle of building up a system as an integrated and economic whole, which might bring actual benefits to its component parts from related operations and unified management," and that the holding companies had burdened the consumer with management, engineering, accounting, publicity, and legal fees, with profits on intercompany sales of materials and construction contracts, and with security charges "beyond the value of the holding company to the industry."

Finally, the report said:

> Attempts by State commissions to protect the consumer from the burdens which holding company practices have imposed upon him have been, and practically always must be, largely unsuccessful. * * * And usually the holding companies have purposely arranged their organization to keep out of reach of State regulation; their lawyers have challenged the jurisdiction of such regulation. * * *

The report recommended Federal legislation regarding public utility holding companies to "eradicate disclosed abuses, prevent the use of the holding company and affiliated interests to obstruct the State regulation of operating companies, and make possible the elimination of the holding company where it serves no demonstrably useful and necessary purpose, without undue dislocation of investment or the loss of operating economies which flow from economically and geographically integrated public utility systems."

The significance of this report in the development of Federal power policy lay primarily in its recognition that the problem of economical integration in the power industry had come to transcend State lines and was, therefore, within the scope of Federal interest.

Public Utility Act

The recommendations contained in these reports, insofar as they required expansion of Federal regulation to include phases of the power business beyond the scope of State regulation, were embodied in the Public Utility Act of 1935.

The preamble of this act declared that "public utility holding companies and their subsidiary companies are affected with a national public interest" and that "the national public interest, the interest of investors in the securities of holding companies and their subsidiaries and affiliates, and the interest of consumers of electric energy and natural and manufactured gas, are or may be adversely affected" by a series of holding company abuses. Among the abuses specifically enumerated were: (*a*) extension of holding companies and integration of operating companies bearing no relation to economy of management and operation; (*b*) lack of economy in management, operation, and in the raising of capital for public utility companies, and (*c*) lack of effective public regulation.

Title I of the act gave the Securities and Exchange Commission broad powers over the acquisition of the securities or assets of public utility companies, but directed the Commission to disapprove of the acquisition of such utility securities or assets unless it "finds that such acquisition will serve the public interest by tending towards the economical and efficient development of an integrated public utility system."

The Commission was further directed to preside over the simplification of holding company systems and, to this end, to require, with certain exceptions, each registered holding company to take the necessary steps to limit its operations "to a single integrated public utility system, and to such other businesses as are reasonably incidental, or economically necessary to the operations of such integrated public utility systems." It gave the Commission further authority to eliminate the intercompany transactions and charges which had tended to impose unwarranted costs on the industry.

Title II of the act imposed on the Federal Power Commission a share of the responsibility for the economic integration of the power business. It declared that "the business of transmitting and selling electricity for ultimate distribution to the public is affected with a public interest," and that "Federal regulation of matters relating to generation * * * and of that part of such business which consists of the transmission of electric energy in interstate commerce and the sale of such energy at wholesale in interstate commerce is necessary in the public interest."

In order to assure an abundant and economical supply of electric energy throughout the United States and to provide for the proper conservation and utilization of natural resources, this title of the act directed the Commission "to divide the country into regional districts for the voluntary interconnection and coordination" of power facilities. It assigned the Commission the duty of promoting such interconnection both within and between the separate districts.

The act envisaged the probability that the application of the broadened Federal power policy would require further legislation and directed the Federal Power Commission to continue the investigations regarding the generation, transmission, distribution, and sale of electric energy, initiated as the "Federal Power Survey," in order that the information necessary for recommending such legislation might be secured.[1]

Congress thus extended the Federal power policy to include provision for a complete and continuing inventory of the entire power industry. As a result of this provision the country will be constantly supplied with authoritative information as to the conduct of this essential public service.

Marketing Power From General River Basin Projects

The preceding discussion summarizes the investigations, reports, and legislation through which the Federal Government has been progressively broadening its power policy to deal with problems which had been becoming more and more pressing as a result of the trend of the industry during the preceding decade. Attention has been directed chiefly to planning for the development of hydroelectric power as part of the general conservation program, to extending Federal regulation with special emphasis on integration of the power business on a sound economic basis, and to providing for a continuing survey of all aspects of the Nation's power supply as a basis for future planning.

Simultaneously, as part of its public works program, the Federal Government was actually proceeding with a broad water resource conservation program which included construction of dams for flood control, navigation, and irrigation. These great river basin projects could not be undertaken by private enterprise. In most instances they transcended State borders. They could be undertaken in a satisfactory manner only by the Federal Government.

The Federal Government could not ignore the fact that the construction of such dams would make possible the economical development of hydroelectric power on a large scale. In fact, the National Resources Board (Committee) had emphasized the importance of power in such programs, stressing the point that the use of all available water power tended to conserve the country's exhaustible energy resources.

The Government was under obligation to market the power thus developed in connection with its broader conservation program, in such a manner as to assure the people the greatest possible advantage from their water-power resources. This necessarily involved the setting up of agencies with authority to build the transmission lines required to deliver the power to resale agencies for distribution in accordance with the governmental purpose.

The National Resources Board (Committee), as already pointed out, had called attention to the Government's interest in extending the use of electricity and in reduction of rates to bring about such increased consumption. The marketing of Government-owned hydroelectric power afforded an opportunity to test the possibility of progress along this line. Municipally owned systems distributing the power would serve as experiments to demonstrate the economic soundness of promoting increased consumption through low rate schedules and would, thereby, make modern standards of economy in the distribution of electricity an effective influence on the power industry.

These experiments in the marketing of hydroelectric power, produced in connection with general river basin development projects, have been popularized under the conception of a "yardstick" for electric rates. They have attracted public attention chiefly in connection with the work of the Tennessee Valley Authority.

The "yardstick" idea in itself represented no innovation. For many years important municipalities had operated isolated publicly-owned power systems, in many instances competing with private utilities. Such municipal plants, when imbued with the "yardstick" purpose, had proved effective in assuring lower electric rates than could generally be obtained through the processes of regulation, the lower rates being characteristic not only of the public plants themselves, but also of the competing private systems. Thus, the first rate survey of the Federal Power Commission showed, broadly speaking, the lowest residential rates in cities where actual or potential public competition could be definitely shown to have been an important influence.

The encouragement of municipal "yardstick" power undertakings, as a market for Government hydroelectric power, modified the well-established principle of municipal operation only to the extent necessary to conform to the changes in the power industry itself. As a result of these changes municipalities no longer faced local companies representing local capital but great interconnected systems backed by the resources of national financial combinations wielding enormous influence. Although the Federal Government uses its power supply to assure such municipal undertakings wholesale power at a cost comparable with that attainable by a conservatively financed interconnected system, the "yardstick" remains essentially the municipal distribution system.

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[1] The comprehensive character of the work thus assigned to the Commission appears in the following extract from sec. 311 of the act: "* * * It shall, so far as practicable, secure and keep current information regarding the ownership, operation, management, and control of all facilities for such generation, transmission, distribution, and sale; the capacity and output thereof and the relationship between the two; the cost of generation, and contracts in respect of the sale of electric energy and its service to residential, rural, commercial, and industrial consumers and other purchasers by private and public agencies; and the relation of any or all such facts to the development of navigation, industry, commerce, and national defense. The Commission shall report to Congress the results of investigations made under authority of this section."

In general, the adoption of this plan represented merely an adaptation of the principle, embodied in the Federal Power Act of 1920, assuring States and municipalities a preferential right to the development of water-power resources. Such adaptation was necessary because regional water resources programs could only be undertaken by the Federal Government.

The Tennessee Valley Authority

The Tennessee Valley Authority Act, as an expression of Federal power policy, directed the Authority (1) to generate and sell electricity, in quantities consistent with stream-flow regulation primarily for the purposes of promoting navigation and controlling floods, in order to avoid waste of water power; (2) to give preference in the sale of this surplus power to States, counties, municipalities, and cooperative organizations of farmers and others not organized or doing business for profit; (3) to construct or acquire transmission facilities to provide outlets for the sale of power; and (4) to promote the wider and better use of electric power for agricultural and domestic use and for the development of the resources of the region.

Under this act the Tennessee Valley Authority is developing an interconnected wholesale power supply system from which municipal, cooperative, and other public bodies in the Valley can secure power for resale at costs in keeping with modern technical standards. In the contracts for purchase of this Government power for resale, the distribution agencies agree to apply experimentally the T. V. A. standard rates.[2]

These standard rates constitute the "yardstick" because their experimental application by municipalities and cooperatives determines (*a*) the effect of such rates in making possible greatly increased use of electricity, and (*b*) whether they produce sufficient revenue to cover all necessary costs of providing service on an economical basis. For residences they result in the following bills:

Kilowatt-hours per month:	*Monthly bills*
50, lights and small appliances	$1.50
100, lights, small appliances, and refrigerator	2.50
250, lights, small appliances, refrigerator, and range	5.00
500, lights, small appliances, refrigerator, range, and hot-water heater	6.90

In its Statistical Bulletin No. 1, dealing with the first results of these "yardstick" rates in Tupelo, Miss., the Tennessee Valley Authority set forth the general purpose as follows:

> The rate policies of the Tennessee Valley Authority are predicated upon volume, and all of its efforts are directed toward securing a wider and better use of electricity. The low price of electricity induces customers to make liberal use of electric services wherever they are desired. * * * With the expanding use of electricity the costs of generation and distribution per unit of energy sold are found to decrease. In principle, it was necessary first to set forth rates sufficiently cheap and properly designed as to form, in order that customers might be able to use electric power. When these rates were made available, the public did not hesitate to take advantage of the services and to increase consumption.

In its 1936 annual report, the Authority stressed the importance of actual demonstration (1) that the electric power industry had become involved in a vicious circle of high prices and low consumption, and (2) that there was a means of escape from this predicament through application of the price policy generally adopted in mass-production industries. It pointed to the extraordinary increases in residential consumption following the establishment of lower rates as indication that the vicious circle had been broken.

The Authority's 1937 annual report emphasized the fact that the great reductions in the ultimate consumer's bill, amounting to several cents per kilowatt-hour, are found chiefly in the policies of the local distributors after they have paid the T. V. A. wholesale price. It pointed out that the experiment had proved the actual cost of local distribution to be far less than had generally been supposed.

Municipal Retail Agencies Provide Yardstick

The extent to which this plan for disposal of Government developed hydroelectric power has succeeded in establishing new standards, both for the cost of distributing electricity and for higher retail consumption, can only be measured by the actual experience of the T. V. A. resale agencies applying the standard rates. Fortunately, although the normal development of distribution under the T. V. A. Act has been hampered by constant litigation, the preliminary results from the operations of 15 municipalities purchasing T. V. A power for resale during the year ended June 30, 1938, are available for analysis. The essential data may be summarized as follows:

1. The average residential consumption of electricity in the 15 municipalities ranged from 995 kilowatt-hours per year in Milan, Tenn., to 2,666 kilowatt-hours in Muscle Shoals, Ala. For 12 out of the 15 municipalities the average annual use was over 1,200 kilowatt-hours. The weighted average for the entire group was 1,600 kilowatt-hours, or 133 kilowatt-hours a month. This compares with residential consumption for the United States as a whole averaging 793 kilowatt-hours, or

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[2] T. V. A. standard residential rates: First 50 kilowatt-hours per month at 3 cents per kilowatt-hour; next 150 kilowatt-hours per month at 2 cents per kilowatt-hour; next 200 kilowatt-hours per month at 1 cent per kilowatt-hour; next 1,000 kilowatt-hours per month at 0.4 cent per kilowatt-hour; excess over 1,400 kilowatt-hours per month at 0.75 cent per kilowatt-hour.

Minimum monthly bill: 5 ampere meter, $0.75; 10 ampere meter, $1; 50 ampere meter, $1.50.

about 66 kilowatt-hours a month, in 1937; and 850 kilowatt-hours, or 71 kilowatt-hours a month, in 1938.

2. The average residential electric rates for the 15 municipalities ranged from 1.6 cents per kilowatt-hour in Muscle Shoals to 2.7 cents per kilowatt-hour in Milan. In all but 2 of the municipalities it was under 2.5 cents and in 7 it was under 2.0 cents. The weighted average for all residential customers served by these municipalities was 2.0 cents per kilowatt-hour. This compares with an average residential rate for the United States as a whole of 4.1 cents in 1937 and 4.2 cents in 1938.

3. The average annual residential bills for the 15 municipalities ranged from $24.07 in Amory, Miss., to $42.64 in Muscle Shoals. In 10 of the municipalities the average was over $30 and for the entire group the weighted average was $31.40. In other words, although the experiment in drastic rate reduction is still young, the average residential bill is already very little below the average for the country as a whole in 1933, the year in which the T. V. A. was initiated. The difference is that the average service rendered homes by these municipalities is approximately 2½ times that rendered for the same average bill by electric systems throughout the country in 1933.

4. These municipalities paid the T. V. A. an average of 5.4 mills per kilowatt-hour for wholesale power supply in the year ended June 30, 1938, representing a reasonable charge for such power supply in the region, and comparing with an average of 4.8 mills per kilowatt-hour at which the Alabama Power Co. sold 856,366,000 kilowatt-hours to other private utilities for resale in 1937.

5. These municipalities paid an average of $10.30 per customer in distribution expenses in the 12-month period, which compares with an average of $10.42 for the same expenses for 18 municipal plants outside of the T. V. A. area and with $9.85 for 281 municipal systems distributing power in Ontario.

6. The fixed capital of the 15 municipal distribution systems averaged $140 per kilowatt of peak load, comparing with the figure of $118 per kilowatt of peak load which President Kellogg of the Edison Electric Institute gave the Congressional Committee investigating the T. V. A. as representing the corresponding distribution fixed capital for private systems throughout the United States.

7. The net operating income of the 15 municipal systems for the 12-month period, after paying for wholesale power supply and for all operating, maintenance, and administrative expenses, was equivalent to 20.4 percent on their total fixed capital, less depreciation. This was sufficient to provide for depreciation, taxes, and a return of approximately 15 percent, or more than double the assumed fair return asked by private capital.

In other words, the results of the T. V. A. experiment so far indicate that the standard resale rates, set up to determine new standards of cost and use, have had the effect of promoting an increase in average residential consumption to levels already approximately double the average for the country as a whole. At the same time they have provided sufficient gross income to cover all necessary costs of power supply, distribution expenses, and, in addition, fixed charges considerably in excess of those necessary to provide for depreciation, taxes, and a 6-percent return on a reasonable distribution investment.

The private companies immediately affected by the T. V. A. undertaking, prior to the actual announcement of standard rates by the Authority, lowered their rates and have lowered them still further since. As a result, they have experienced the greatest increase in residential sales in the private power industry.[3] Throughout the country many cities, served by private companies, now have electric rates which are rapidly coming down to levels corresponding with the T. V. A. standards.[4]

Rural Electrification

Discussion of the extension of Federal power policy, to include the establishment of new standards in the power industry, would be incomplete without reference to the work of the Rural Electrification Administration. It has concerned itself especially with new standards of economy in rural line construction and with new standards of farm use, designed to demonstrate that electricity should be an economic asset, instead of an added cost, to the families engaged in agriculture.

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[3] While the average residential use of electricity in the United States increased from 600 kilowatt-hours in 1933 to 792 kilowatt-hours in 1937, the corresponding increases for these companies have been as follows: Alabama Power from 808 to 1,205; Georgia Power from 805 to 1,313; and Tennessee Electric Power from 612 to 1,352 kilowatt-hours a year. The average residential rate for these three companies in 1937 was just about 3 cents per kilowatt-hour as compared with the average of 4.4 cents for the United States as a whole, but they collected an average annual bill of $39.00 from these customers, or $4.20 more than the $34.80 representing the average annual residential bill for the entire country.

[4] T. V. A. standard residential rates for 100 and 250 kilowatt-hours a month compare with those in certain cities served by private companies as follows:

Residential rates	Monthly bills	
	100 kilowatt-hours	250 kilowatt-hours
T. V. A. municipalities	$2.50	$5.00
Cincinnati, Ohio	2.50	4.75
Covington, Ky	2.50	4.75
Madison, Wis	2.60	5.10
Washington, D. C	2.85	5.10

The length of this memorandum does not permit extensive discussion of the progress in rural electrification since the Administration was established in 1935. Brief reference, however, must be made to the success achieved in reducing the cost of constructing rural lines, because it illustrates clearly both the necessity for the extension of Federal power policy into the field of standards and the results which have followed. Dealing with this, the 1937 report of the Rural Electrification Administration says:

> The continuing spread of rural electrification is dependent upon steadily declining costs. Every time the cost of bringing central station electric service to the farm drops, the number of farms which can be reached on a self-liquidating basis goes up. It is the job of the R. E. A. Engineering Division, as it supervises the construction of R. E. A. projects, to translate a substantial part of this proposition into fact.

Summarizing the results already obtained, the report states that a group of R. E. A. projects recently released for construction averaged approximately $850 per mile, as compared with costs ranging from $1,500 to $2,000 per mile for rural lines giving comparable service before the R. E. A. entered the picture. It states further, that the average cost of all R. E. A. projects is approximately $970 per mile, including projects whose construction costs per mile have ranged from under $700 to over $1,200.

Rural electrification thus affords perhaps the simplest picture of the extent to which high costs had developed in the power industry because, under regulation the incentive to keep costs down has been lacking. The high costs were a barrier to the extension of rural lines. The broadening of Federal power policy to include actual financing of projects, demonstrating new standards of economy, has resulted in the removal of that barrier and the achievement of important progress in the field of rural electrification by both public and private agencies. At the same time, many of the barriers contained in the old rural electrification plans of the private companies have been removed.

The end of 1938 saw 70,000 miles of R. E. A.-financed rural lines in operation. These lines served 150,000 rural customers of whom more than 85 percent were farmers. Altogether, the number of the country's farms receiving electricity increased from 743,954 at the end of 1934 to an estimated 1,410,000 at the end of the first 10 months of 1938. In other words, the number of new farm customers added during the 4 years operation of R. E. A. has closely approximated the total number to which electric service had been extended in all the years preceding its establishment.

Economic Significance of Effort to Establish Cost Standards

The extension of Federal power policy, in connection with the marketing of power from Federal river basin developments, has been widely discussed by experts outside the governmental agencies immediately concerned. The views of a number of them are of sufficient importance to warrant consideration here.

Professor B. Alden Thresher, of Massachusetts Institute of Technology, addressing a recent symposium on power costs conducted by the American Society of Civil Engineers, definitely related the direction taken in the broadening of the Federal power policy to the inadequacy of regulation. He suggested that the accepted scheme of regulation in the United States is, by its very nature, static and ill-adapted to the economic and technical changes characteristic of the power industry.[5]

Vice President Leverett S. Lyon of the Brookings Institute, taking part in the same symposium, attributed the introduction of the "yardstick" policy to the lack of any satisfactory cost basis for fixing rates under regulation.

Mr. Lyon pointed out that in a competitive field, as contrasted with the monopolistic utility business, the costs of an individual company may have no direct relation to the prices at which it can sell its product; that it does high-cost companies no good to complain that their costs will not permit them to compete profitably; that, in such a situation a high-cost manufacturer has no choice but to forget part of his costs, closing his eyes to some of his fixed charges and accepting the fact that his investment is not worth as much as he thought it was.

He stated that a buyer should be in a position to purchase, at any time, at as low a price as anyone will offer, if the resources of the Nation are to be used so as to give the greatest possible output for the smallest possible input. He held that the theory that prices should cover costs is in conflict with this objective and provides "no incentive to keep costs down."

Mr. Lyon then asserted that in the field of power, because it is a natural monopoly, the competitive method of price determination will not apply and that, since a monopoly cannot be trusted to create prices in the public interest, social regulation of rates has been established in every State. He continued: "Since the commissions which have been given this responsibility have no competitive tests they have groped none too happily, in an effort to relate costs to prices."[6]

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[5] Professor Thresher said:

"It is more accurate, therefore, to regard the Federal power program, whatever its merits or defects, as a response to a long-standing maladjustment, not as a punishment meted out to malefactors. The machinery of State regulation is often said to have 'broken down.' More strictly speaking, it has always lagged behind the situation with which it strove to grapple. This was true even in the days of local power units, because of the rapid rate of technical change. It is doubly true now that regional interconnections extend over areas beyond the jurisdiction of regulative authorities."

Mr. Lyon concluded:

> It is the raising of such issues of costs as these which has introduced the now much discussed "yardstick" as a proposed method of determining what prices should be. Of course, the so-called "yardstick" is not a new idea. Every method that can be applied to determining what prices shall be—even competition—is a yardstick; but the great extension of government operations as a means of comparing costs does offer, in size at least, something new * * *.

The Federal policy, adopted for the marketing of hydroelectric power, is already establishing in the power business cost standards based on the best economy achievable by modern technology. In effect, it provides the same incentive to keep costs down as prevails in a competitive industry, in which new competitors may be expected whenever existing operators become unprogressive. It tends to prevent the pegging of rates to obsolescent or otherwise excessive costs.

Actuarial Expert Fergus J. McDiarmid, associated with the Lincoln Life Insurance Company of Fort Wayne, Ind., writing for the October 14, 1937, issue of Public Utilities Fortnightly, points out that "probably the closest historical analogy to the situation, now facing certain private utilities in the Tennessee Valley and elsewhere, is that faced about 20 years ago by the private electric company serving Ottawa, Canada." At that time, according to Mr. McDiarmid, this company met the competition of the Ontario Hydro-Electric Power Commission by dropping rates to rock bottom, that is, to a level considerably below those of the Tennessee Valley Authority. He compares the Ottawa residential rates with those of T. V. A. as follows:

Monthly domestic bills

	100 kilowatt-hours	250 kilowatt-hours	500 kilowatt-hours
T. V. A.	$2.50	$5.00	$6.90
Ottawa electric rates	1.74	2.80	3.90

Mr. McDiarmid reports that, after more than 20 years, the private company has approximately twice as many customers as the public system and that its 1935 earnings, after depreciation, represented a return of more than 9 percent on the depreciated book value of its property. He states that the company is on the most friendly terms with its publicly owned competitor.

In terms of the governmental concern for expansion in the use of electricity, it may be noted that in 1937 residential consumption in Ottawa averaged 340 kilowatt-hours a month, or 4,080 kilowatt-hours a year. Ottawa homes paid an average of $3.07 a month for electric service, as compared with $2.92 a month paid by homes in the United States. But for $3.07 they received approximately five times as much service, 340 as against 66 kilowatt-hours. Their average rate was 0.9 as against 1.4 cents per kilowatt-hour in this country.

In Ottawa competition has provided a continuing incentive to economy and efficiency of operation, enabling consumers to secure the maximum of electric service for their dollar.

The views of these professional economists, with reference to the Federal power policy under discussion, may be interpreted as follows:

1. Use of the Nation's power resources to the best advantage in the public interest can only mean assuring the people the largest possible use of electricity at the lowest possible cost.

2. In competitive industry the matter of assuring the people the greatest possible supply at the lowest possible cost is taken care of by the fact that the low-cost company will get the business unless high-cost companies readjust their conception of necessary costs.

3. Price fixing on the theory that prices should cover costs leads to the greatest difficulties, especially as it provides no incentive to keep costs down. It may even become an incentive to higher costs.

4. Regulation of private power monopolies has failed to find a substitute for competition to assure the people electric service at the lowest possible cost. Its procedure, involving rates based upon the costs of individual companies, has opened the way to a wide variety of practices making for excessive costs. The resulting high rates have tended to restrict consumption contrary to the public interest.

5. The government yardstick policy is merely an adaptation to the power business of the competitive yardstick which has been the symbol of sound economy in private business. It creates a situation in which high-cost power undertakings, even though not necessarily directly affected by public competition, will increasingly have to readjust their conception of necessary costs to new standards of economy and efficiency.

6. In Ottawa, Canada, where a similar policy has been effective for more than 20 years, households are today purchasing an average of 340 kilowatt-hours a month for an average monthly bill only 15 cents higher

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[6] This, Mr. Lyon suggested, raises issues of public importance, such as: "whether costs are fair or unfair? Are they really necessary costs or are they padded? Is the enterprise capitalized at the minimum necessary to furnish the service or is it overcapitalized? Are officials overpaid or otherwise? To what extent are holding companies and similar financial and managerial mechanisms an effective means of organization and operating, and to what extent, if any, are they means of adding costs, positions, and salaries, on which rates are computed?"

than the average home in the United States pays for 66 kilowatt-hours, and the private company has been making a reasonable profit.

Viewed in terms of this analysis, there appears to be substantial justification for the policy adopted by the Federal Government for marketing hydroelectric power developed in connection with its water resource conservation program.

Problem of Allocation of Costs in Relation to the Economics of Federal Hydro Projects

The problem of allocating costs in connection with multipurpose projects, in so far as it has been assumed to control rates, has produced difficulties comparable with those that have been associated with attempts to determine so-called fair value for rate-making purposes. For this reason the following thoughts are offered, not as a definitive statement of Government policy but to provoke discussion with a view to later formulation. They are suggested by a discussion of the question in the National Resources Committee report, *Drainage Basin Problems and Programs, 1937 Revision.*

Although the Committee holds to the theory that "the allocation of costs should be made with proper regard to the benefits afforded by a project and the revenues from the sale of power should be based on the cost thus allocated," it recognizes that "adjustments of the allocations of costs should be made from time to time, since the relationship among the several benefits may be affected by changed conditions" and adds that "allocation of joint costs is usually a matter of judgment involving an appraisal of social and economic values and not ordinarily a matter determinable by any definite accounting formula."

Discussing allocation further on the basis of an evaluation of relative benefits, the Committee points out that power rates, fixed below the level of power costs naturally inherent in the region, might result in "an unwarranted burden upon national taxpayers for the benefit of specially favored groups or localities," while on the other hand, "the costs allocated to power cannot be so large as to result in power rates higher than the inherent power production cost levels of the region, because the project power could not be marketed at such rates." The Committee concludes:

> Estimates of the value of power from a project should be based upon the costs of power from alternative sources, either steam-electric plants or other hydroelectric plants, so planned as economically to supply the future needs for power in the area. The estimates of costs of power from steam-electric plants should include consideration of future costs of fuels and their effect upon the design of plants and the future capital cost of plants.

This raises the question whether practical procedure might not establish first the wholesale rates for power from multipurpose Government projects on the basis of the most economical possible alternative power supply in the region and then determine, on the basis of the revenue to be derived from such rates, the portion of the cost of the entire project which power could sustain.

On this theory, in most regions the determining factor in the establishment of wholesale rates, for power supply from transmission lines interconnecting Federal hydro developments, would be the cost of equivalent power supply from the best modern steam stations in the region. This would follow the precedent set by the private power industry which, in the past, has capitalized water-power developments on the basis of alternative steam costs. Provision should be made, however, for periodic readjustment of such rates in conformity with changes due to technological progress, as well as for ultimately giving the people the advantage of amortization of the project cost.

If this principle should be adopted, matters of cost allocation between irrigation, flood control, navigation, and power should not adversely affect private power systems. Consequently, such power interests could not fairly object to a program which would accelerate the construction of hydroelectric projects as part of a public works program to absorb unused labor in periods of depression and unemployment.

The economy of public hydroelectric power development, in conjunction with general river basin programs, under such circumstances, may be outlined as follows:

1. Hydroelectric projects provide power supply with a minimum of current operating costs and therefore with a minimum expenditure of social energy during normal periods of business activity and employment. This is also true of the operation of interconnecting transmission systems. In both instances the annual cost is chiefly represented by the fixed charges on investment, including depreciation and/or amortization.

2. Such projects, in periods when provision for work relief to support workers otherwise unemployed becomes a necessary social cost, assure that such public employment will make an enduring contribution to the future welfare of the Nation. Once constructed they will continue indefinitely to deliver power at low operating costs.

3. If the annual revenue from the sale of such power, at wholesale rates based on the cost of the best equivalent modern steam supply, is sufficient to cover the cost of maintaining and operating the generating stations and transmission lines, together with charges for depreciation and amortization, such power projects will have

provided for the ultimate repayment to the country of the cost of the work relief involved in their construction. Everything which they earn above this will serve to amortize costs incurred for other purposes such as irrigation, flood control, and navigation.

On this basis the Federal water power program would attain new flexibility without being open to the charge that it offered unfair competition with existing private systems. Hydroelectric developments, not economically feasible in terms of the cost theories of private enterprise, would become of the highest social and economic value as part of the Nation's employment stabilization program.

A Glance at the Future

Federal power policy may be expected to develop along the lines indicated in this historical summary to the extent which may prove necessary to assure the people the maximum use of their power resources at the lowest possible cost, with full regard for the necessity of conserving the Nation's exhaustible sources of energy supply. As a result of changes in the power industry itself, these lines of development have come to include:

1. Protection of the consumer and investor interest in the economical and efficient integration of public utility systems on a regional basis, insofar as such integration transcends State lines and consequently comes within the scope of Federal responsibility.

2. Continued encouragement of the extension of rural electric lines throughout the Nation and of new standards for farm use of electricity, designed to render electric service an economic asset to families engaged in agriculture.

3. A continuing survey of the generation, transmission, and distribution of electrical energy, including all data with reference to the Nation's power facilities, resources, and requirements necessary for planning in advance for the construction, by public or private agencies, of the power plants and transmission facilities needed to assure all regions ample power supply in peace and in war.

4. Recognition that, in the development of any long-range plan for meeting the Nation's future power requirements on the most economical basis, full consideration must be given to the importance of conserving energy resources which are subject to depletion.

5. Development of all economically available water power in connection with river basin conservation programs, and provision for marketing the power in such a way as to assure the low resale rates necessary to bring about a wider and better use of electricity, in order that the people as a whole may secure the greatest possible advantage from their water power resources.

Power from many hydro developments can be most economically marketed in coordination with the output of steam-electric stations. This coordination should be obtainable, in the main, through the cooperation of private and municipal power agencies on terms conformable with the requirements of Federal power policy. Where such coordination is not available the Federal power policy may have to include the construction and operation of some steam capacity to make possible the most efficient marketing of Government hydroelectric power.

Finally, in approaching the question of future Federal power policy, it should be possible for all concerned to agree that, in an industry as vital to the general welfare as that of power supply, the public interest in maximum use can be the only basis for a choice between alternative theories of operation. Ultimately, Government must be able to adopt whatever methods prove necessary to subserve the fundamental interest of the people as a whole in the most advantageous use of their power resources.